Seven Decades of Astronomy and Optics:

From Knife Edge to Interferometers;

From Earth to Space

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24 July 2014

HOUSTON RESEARCH ASSOCIATES

SCIENCE TECHNOLOGY

The 2014 Stellafane Convention

John, Members of the Organizing Committee, Fellow TNs and friends of Stellafane, it is an honor to be a part of the 2014 convention which celebrates its 88th birthday this year. Stellafane has always been at the heart of my seven decade career in optics and astronomy. Today I will share some highlights of that career with you as a means of passing the torch.

I am deeply indebted to two individuals who are here today: first, John Briggs, not only for inviting me to participate in this celebration, but also kindly presenting this talk on my behalf; secondly, Bert Willard, who authored one of my most cherished books, “Russell W. Porter: Artic Explorer – Artist – Telescope Maker.”

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EARLY MENTORS

- Michael Baranelli – High School Physics Teacher
  - Encouraged interest in Astronomy and questioned convention
- Dr. William Glenn – Birmingham Southern Faculty
  - Provided opportunity to use college's student observatory
- C. C. Pinckney – Retired Mechanical Engineer
  - Built an 8-inch telescope and provided my first view of Saturn

My first mentors were an inspirational high school teacher, a professor at the local college, and a retired engineer friend who built his own telescope…..

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PLANET SATURN

and allowed me to see my first celestial object!

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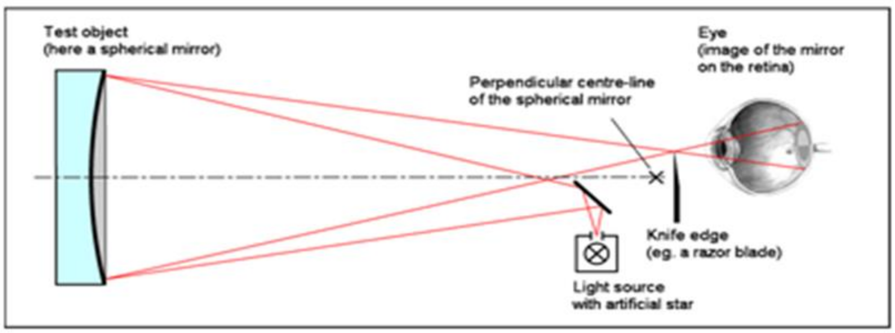
FOUCAULT TEST



At age 13, inspired and encouraged by these mentors, I decided that I could build a telescope.

My first mirror blank was acquired from Precision Optical Company (ad in Sky & Telescope circa 1949). I ground, polished and figured this blank into a parabola using a home-made, knife-edge tester (illustrated on p. 6 and 7 in ATM Book 1). So began my experience in the optical shop which became addictive!

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My subsequent decision to major in Astronomy met with skepticism. In my environment in the 1940s Astronomy was considered a worthwhile hobby, but not an acknowledged career field. The most common response was why not major in engineering and "tell fortunes on the weekend?"

Determinedly, I persevered and located a newly minted undergraduate program at the University of Texas in Austin established by Ervin J. Prouse from Berkeley; and

Frank N. Edmunds, Jr. from Princeton and the University of Chicago. Dr. Prouse specialized in Celestial Mechanics and Advanced Mathematics; Dr. Edmunds taught Astrophysics as well as supporting the founding of the Forty Acres Astronomy Club. With an enrollment of five students the program was launched in September 1954.

This new program at UT provided opportunities such as:

- Providing public lectures on Wednesday nights
- Providing technical assistance in the observatory
- Performing calculations for stellar modelling
- Preparing and organizing lesson plans

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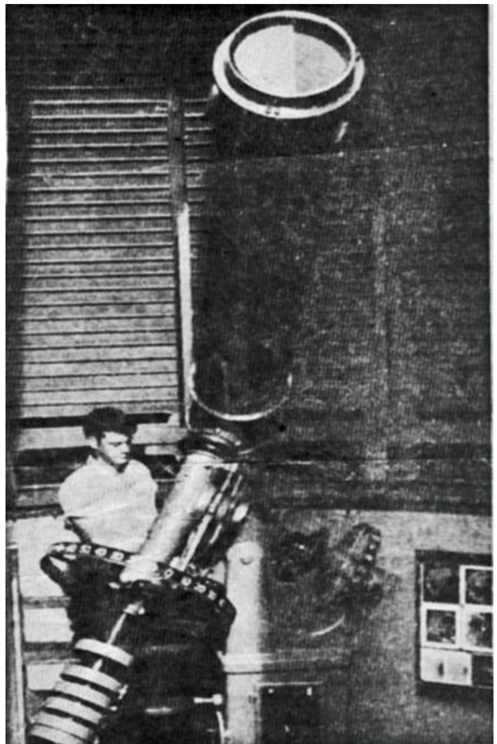

Photo by Paul D. Ho

JOE HOUSTON
. . . a universal view

- and maintaining the 9-1/2 inch telescope!

By late 1955, the other four enrollees returned to the Physics Department, thus offering me multiple jobs. These jobs provided valuable experience in teaching, instrument design and machine shop practices.

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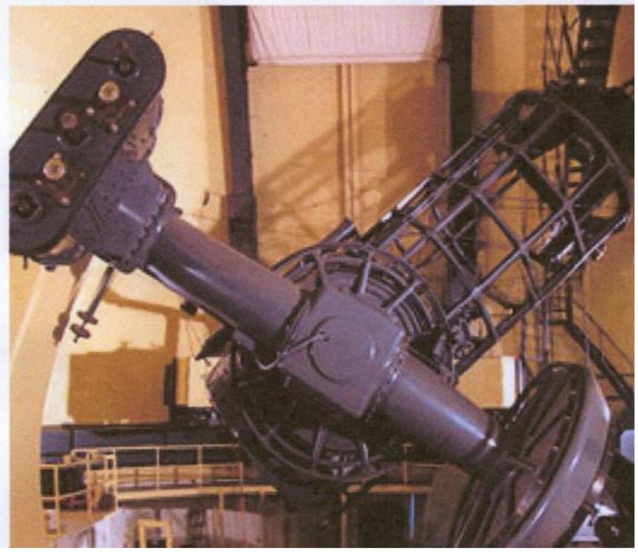

In the spring of 1956 with universal military draft breathing down my neck, I needed to complete my senior thesis on Binary Stars. My thesis advisor, Dr. George van Biesbroeck, Astronomer at the Yerkes Observatory, University of Chicago, required field research at McDonald Observatory, located on Mount Locke in the Davis Mountains of west Texas. Mount Locke was selected as the site for a world-class observatory owing to its high ratio of clear nights, its altitude and "darkness." Two examples: (1) the sky is so dark that the planet Venus easily casts a shadow and, (2) on a clear night, at the observatory's altitude of 6,800 feet, one can see the Southern Cross. Featured in this slide is the landscape around Mt. Locke, two domes….the Otto Struve (left) and the Harlan J. Smith (right)……. and the interior of the Struve observatory with its 82-inch telescope.

McDonald Observatory is 405 miles from the UT campus in Austin with the only public transportation being a Greyhound bus which took over 10 hours to cover that distance in the best of weather. Arriving hot and tired at the bus station in the small town of Alpine, it was a great relief to climb into Dr. van B's station wagon and complete the final 39 mile leg of the journey up the mountain to the Observatory. With the greatest of driving skills, he attacked the incline at roughly 70 miles per hour gaining speed all the way to the top. Shaken, I remembered thanking him for the ride and with even greater relief, heading for the dormitory building to recover. At that time Dr. van B. was a very healthy 76 year old astronomer who made frequent, non-stop drives from Yerkes Observatory in Williams Bay, WI, to the McDonald Observatory in Texas so the drive up the mountain was par for the course for him.

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Early that evening, Dr. van B. suggested a walk around the mountain top to get a breath of fresh air before preparing for the night's work. Exhausted from the trip and newly arrived at a high altitude, I had trouble just catching my breath. Later, during the observing session near midnight, I learned that one of my additional duties, and no doubt the most critical, was to hold Dr. van B. by his belt when he leaned over the guard-rail, at prime focus to change glass plates.

To summarize: the week of all-night observing sessions, developing glass plates, analyzing the plates with a blink comparator, employing classical equations to calculate orbital elements for binary star systems, and continuing the daily “constitutionals” around the mountain top, resulted in a vast improvement in both my mental and physical condition. The week also convinced me that a career in astronomy limited to sitting on a mountaintop, looking through a telescope, would not be a part of my future plans.

In those days, universal military training (UMT) was required of all eligible male students at UT. With a degree in Astronomy, a commission in the Corps of Engineers appeared to be the best choice. Becoming a “rocket scientist” at Redstone Arsenal in Huntsville, AL, ought to be a “shoe-in.” The Army however, in its greater wisdom, had different plans as follows:

NEXT SLIDE – READ TEXT ONLY – NOT PICS

First to Ranger and Jump School………..

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..followed by troop duty at Ft. Polk and flight school..

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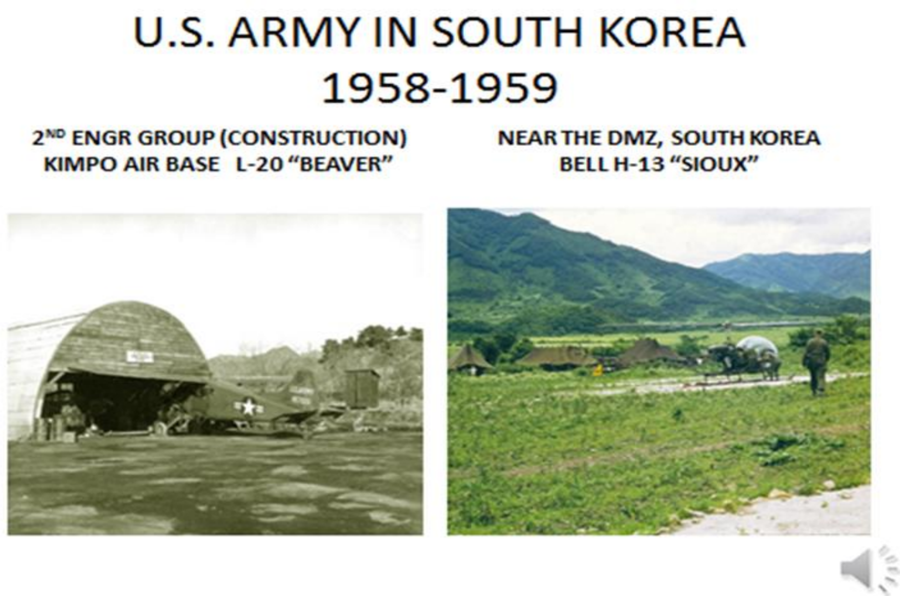
..then helicopter school at Camp Wolters, TX..

NEXT SLIDE

…and finally, a year in Korea.



As they say, "life is what happens when one is making other plans."

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Monterey Peninsula College

Returning to the States in December 1959, to Fort Ord in Monterey, CA, a U.S. Army basic training post, provided a welcomed respite from life in the “boondocks.” I realized that Redstone Arsenal and “rocket scientist” were not in my immediate future. I began to prepare for entering civilian life. Along with my Corps of Engineers duties, I enrolled in advanced math courses at MPC. Inquiring about the availability of Astronomy classes, I learned that no such course was offered. At this point, the Dean suggested that I develop and teach the first one. I did!

In contrast today, Monterey Peninsula College offers multiple Astronomy courses to enrollees in the Physical Sciences Division.

In June 1961, I departed from the Army, drove across the U.S. to Norwalk, CT, and began a new career as an optical engineer, at Perkin-Elmer Corporation in Norwalk, CT.

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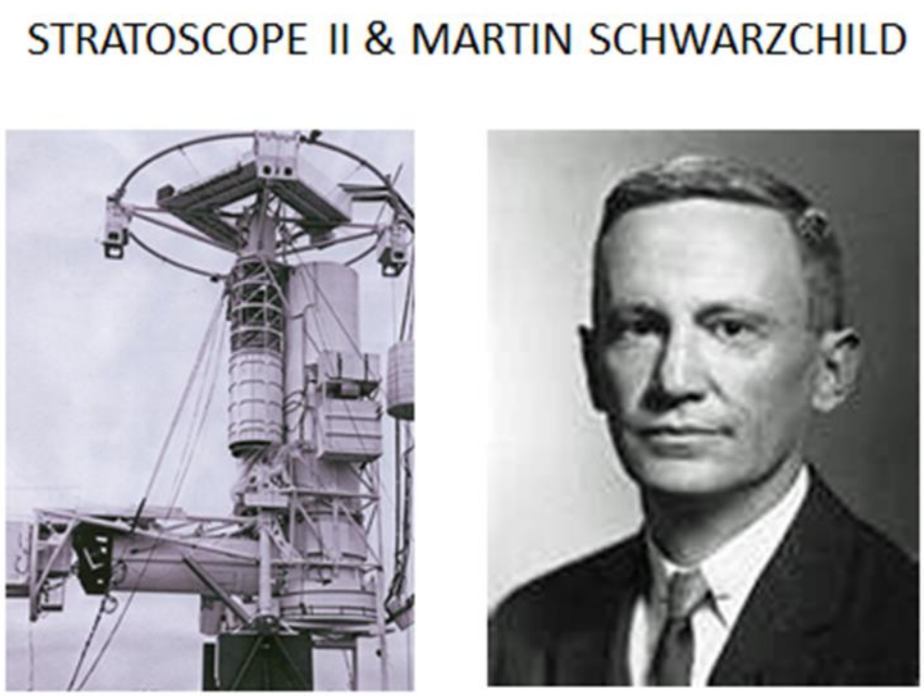

At that time Perkin-Elmer was involved with Project Stratoscope, conceived in the early 1950s during a luncheon with Dr. Lyman Spitzer and Dr. Martin Schwarzchild of Princeton University and Dr. James Van Allen of the University of Iowa. It was agreed that a diffraction limited solar telescope was needed to make real progress in understanding convective processes in the solar photosphere.

After successfully completing the solar photosphere work under Project Stratoscope I, a more ambitious follow-on contract for Stratoscope II was awarded to the Corporation in 1960.

Stratoscope II was designed to explore the heavens from a balloon-borne platform some 80,000 feet above the earth's surface and as its progenitor, establish the science and technology underpinnings for the Hubble Space Telescope. The project was directed by Dr. Martin Schwarzchild, Higgins Professor of Astronomy at Princeton University, with the assistance of Robert Danielson, Princeton University Observatory.

With incredible good fortune I was assigned immediately to the Stratoscope II Project. Not only was I assigned to the project, but I was placed in charge of testing the project's two 36-inch, primary mirrors; one for the "visible" and one for the IR. After a five years absence from anything optical and only one self-taught refresher course in Astronomy, I was reeling from culture shock and a complete change in career and lifestyle. My foremost thought was "what have I gotten myself into?"

After months of searching for an environmentally stable tunnel in which to conduct optical testing…a root cellar would not do….Perkin-Elmer decided to build the first ever vertical vacuum tank. This would allow realistic simulation and characterization of the "visible" mirror's expected performance at 80,000 feet.

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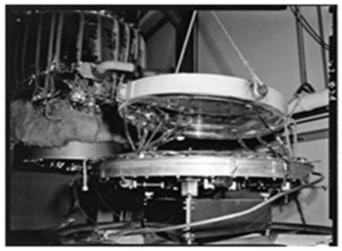
STATUS OF OPTICAL SYSTEMS TESTING IN 1962
Princeton University and Perkin-Elmer Corporation

Vertical Vacuum Tank with ARC Refrigeration
(lowest limit 2 mm Hg and -40 degrees F.)



Final surface contour map of 36-inch Mirror
(in fractions of wavelength of white light)

My assignment to the project was to **<u>quantitatively</u>** verify the “visible” mirror. Using a state-of-the-art James Burch Scatterplate interferometer, I would create a topographic map of the optical surface to within 1/50th wavelength (peak-to-peak) accuracy in the mercury green.

In addition to building the interferometer there was the need for an ideal, 18-point support for the 36-inch primary mirror as well as a null lens which had been conceived and designed by P-E’s master lens designer, Abe Offner. The vacuum chamber required a pump and a “chiller” capable of cooling the mirror to minus 40 degrees C. in less than 2 hours. Also, it needed isolators to eliminate building vibrations. All these components were designed and integrated into a working system that could support a minimum turn-around time for polishing and figuring cycles. The goal was four cycles in a 16 hour work day.

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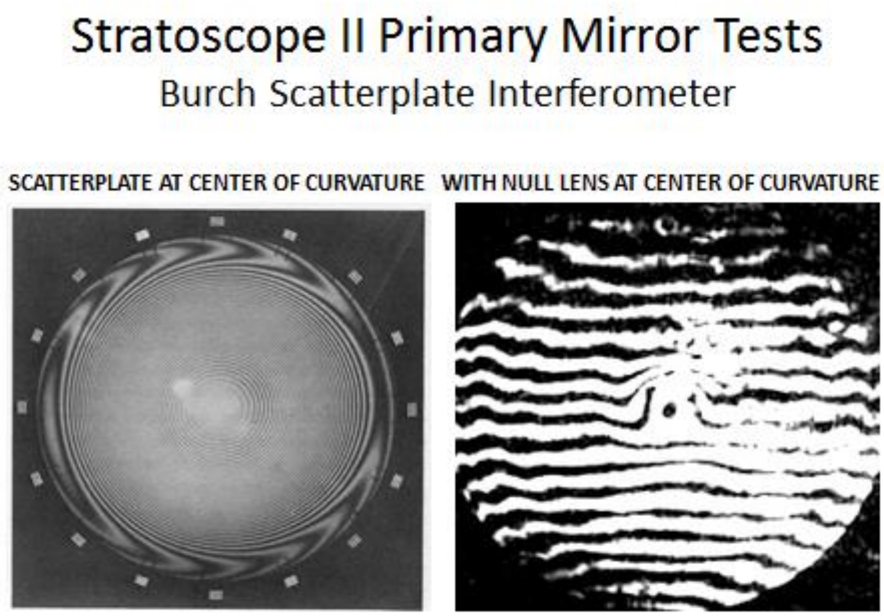

While construction was underway, the mirror was tested at its center of curvature. The dozens of circular interference rings formed as a result of the parabola's departure from a reference sphere were imaged onto a Kodak high-resolution glass plate. The plate was placed on a Mann Comparator and the center of each fringe was measured to an accuracy of plus/minus 1 micron.

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Stratoscope II Test Methodology (1963)

From Recording to Contour Map:

Scatterplate Interferometer

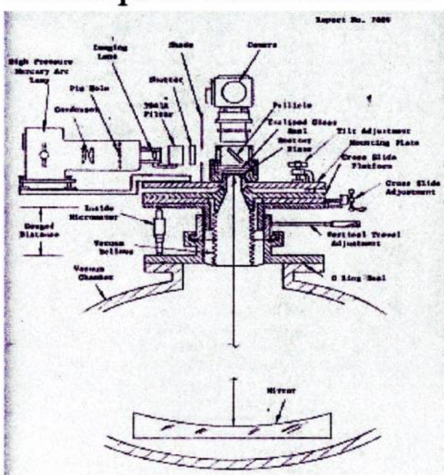

Figure 15. Diagram of the Scatter Plate Apparatus for the Primary Mirror Test

Fringe Scanning Digitizer

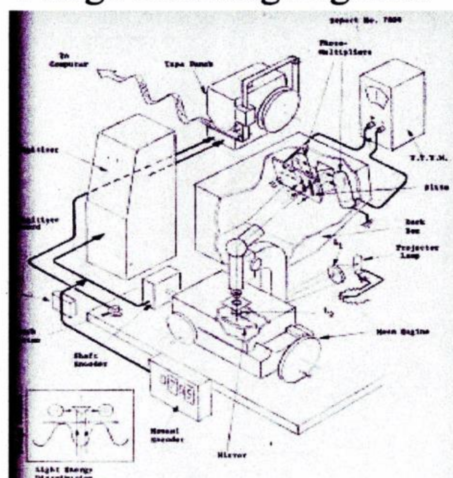

Figure 17. Diagram of the Fringe Measuring Apparatus

Recorded data was fed into an early model of the LGP 30 computer using a primitive algorithm to perform a least squares best fit of the real parabola to a perfect f/4 parabola. The result was a topographic map of the mirror surface. This topographic map was used by Ben Gay, P-E's master optician, as a guide to know where and how much to polish.

On one occasion, when Dr. Schwarzchild was making his monthly visit from Princeton to be briefed on the project's status, he questioned the computer algorithm. With great pride we provided in detail, information about the method and the software we used. Dr. Schwarzchild studied the algorithm closely then writing non-stop for about 15 minutes, generated a different set of equations adding a comment, "that should be much more efficient!" It was not only more efficient but quite humbling!!

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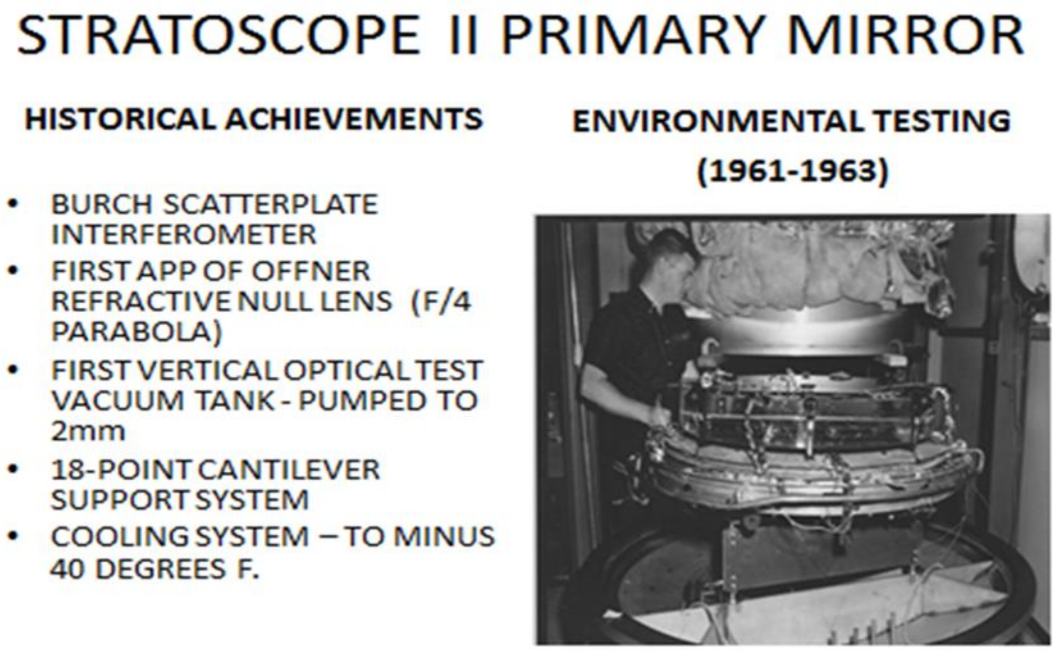

Illustrated and highlighted to the left of the picture are the major achievements of this period.

(OK TO READ HISTORICAL ACHIEVEMENTS)

Month after month of exhaustive 16 hour days of tedious figuring, pumping down the vacuum tank, cooling the mirror, generating interferograms, and reducing the data, the project was finally COMPLETED. What a relief to the exhausted team when Dr. Schwarzchild declared our mirror “the most perfect mirror in the universe.”

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“Most Perfect Mirror”

- Final Inspection before Coating

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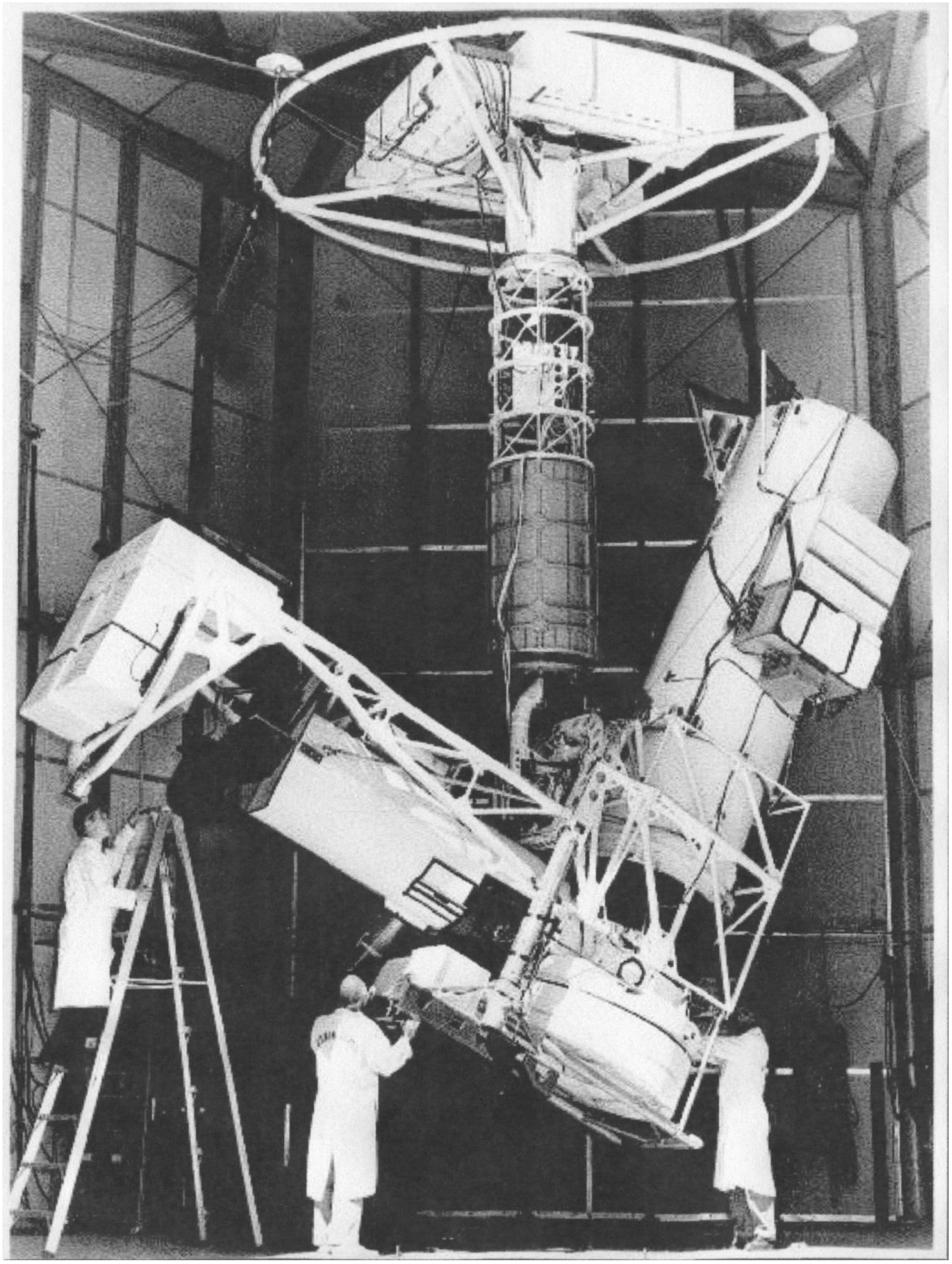

Next step. The mirror was placed in the telescope which is illustrated in this slide. Astronomical investigations were then conducted from this soon to be balloon-borne platform which would be floating at 80,000 feet. Several flights were completed with varying degrees of success. For a complete listing of all missions planned and flown, see appendix for history of the Stratoscope II flights from 1963 to 1971 in the appendix.

BRIEFLY SHOW HISTORICAL FLIGHTS

Appendix 1

History of Stratoscope II Flights – 1963 to 1971

Date	Hour	Flight Duration	Experiment	Payload landing place or cause of the failure
12/12/1962		**14 h**	**STRATOSCOPE II - TEST FLIGHT**	**Separation system failure. Shoot down by Navy fighters off Florida coast, US**
3/1/1963	**17:41 CST**	**11 h 30 m**	**STRATOSCOPE II**	**Near Pulaski, Tenessee, US**
11/26/1963	**16:00 cst**	**17 h**	**STRATOSCOPE II**	**near Kosciusko, Mississippi, US**
6/2/1964	**---**		**STRATOSCOPE II**	**--- No Data ---**
7/23/1965		**---**	**STRATOSCOPE II**	**--- No Data ---**
5/14/1966	**18:30 local**	**---**	**STRATOSCOPE II**	**--- No Data ---**
4/10/1968		**---**	**STRATOSCOPE II - CHECK OF ELECTRONICS AND ANTENNA SYSTEM**	**--- No Data ---**
5/18/1968	**19:55 local**	**---**	**STRATOSCOPE II**	**Near Cushing, Texas, US**
9/12/1969		**F 11 h 15 m**	**STRATOSCOPE II - ENGINEERING TEST TO VERIFY THERMAL REDESIGN**	**--- No Data ---**
3/26/1970		**F 14 h 20 m**	**STRATOSCOPE II**	**--- No Data ---**
2/26/1970		**---**	**RF TEST STRATOSCOPE II**	**Balloon not to be released**
3/26/1970		**F 14 h 20 m**	**STRATOSCOPE II**	**--- No Data ---**
9/9/1971		**F 10 h 50 m**	**STRATOSCOPE II**	**7 miles SE from Bald Knob, Arkansas, US**

Note: Dates underlined indicate flights 1 through 8.

For further information and results, see link:

http://adsabs.harvard.edu/full/1972ApJ...178..887D

Interestingly enough, the very first flight carried a "dummy payload" and inadvertently floated out over the Atlantic Ocean. When it finally began an uncontrolled descent, it was declared a hazard to flight. On December 12th, 1962, the Navy scrambled fighter jets off the Florida coast to shoot it down. The very valuable instrumentation package landed in the ocean, was retrieved by a Spanish trawler, and "liberated" later from Spain. Dick Perkin, founder of P-E said in an interview that this flight was his only project the U. S. government ever shot down!

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LAUNCHED FROM REDSTONE IN 1971

- The Stratoscope II Program was designed to repeatedly launch and retrieve a 3.5 ton astronomical observatory. It obtained high resolution celestial photos and infrared spectral data on the Moon, Mars, and some red giant stars.

Serendipitously, Redstone Arsenal **<u>was</u>** in my future, but NOT as a rocket scientist. The eighth and last launch of this great instrument took place on September 9th, 1971 from Redstone Arsenal in Huntsville, AL. Both flights 7 and 8 were made with the 1/37th wave rms fused silica mirror that was eventually donated to the Monterey Institute for Research in Astronomy (MIRA.)

Along with the list of technical achievements, there is a litany of anecdotes about Dr. Schwarzchild and his adventures in Cajun country, looking for a stray telescope and instrument package. The Stratoscope II balloon was an extremely large, two-stage contraption that allowed the telescope to be "valved down" to a very low altitude where it landed at a sinking rate of about 500 to 600 feet per minute in order to avoid crushing the optics in a parachute-style landing. On one occasion, a "local" asked Dr. Schwarzchild to describe the balloon and telescope that he was trying to locate. Dr. Shwarzchild answered "several stories tall." To which the local replied, "if I seen sumpin dat big, young fella, you wouldn't be seeing me!"

In another instance, when Dr. Schwarzchild became separated from the main search party, the team grew extremely concerned about his ability to deal with the swamp alligators. Knowing Dr. Schwarzchild, it was the fate of the alligators, not Dr. Schwarzchild's welfare, that should have concerned the team.

Upon completion of the Stratoscope II flights, both the "visible" mirror and I landed on the Monterey Peninsula in 1973. Princeton and Dr. Schwarzchild donated the mirror to a group of young astronomers from Case Western Reserve University.

NEXT SLIDE

With this gift they established the Monterey Institute for Research in Astronomy (MIRA) Oliver Observing Station on Chews Ridge near Carmel, CA. In terms of a fully capable instrument, this “visible” 36-inch mirror more than satisfied their requirements. As Dr. Cynthia Irvine, President of MIRA and one of MIRA’s founders said,” I thought I’d died and gone to heaven.”

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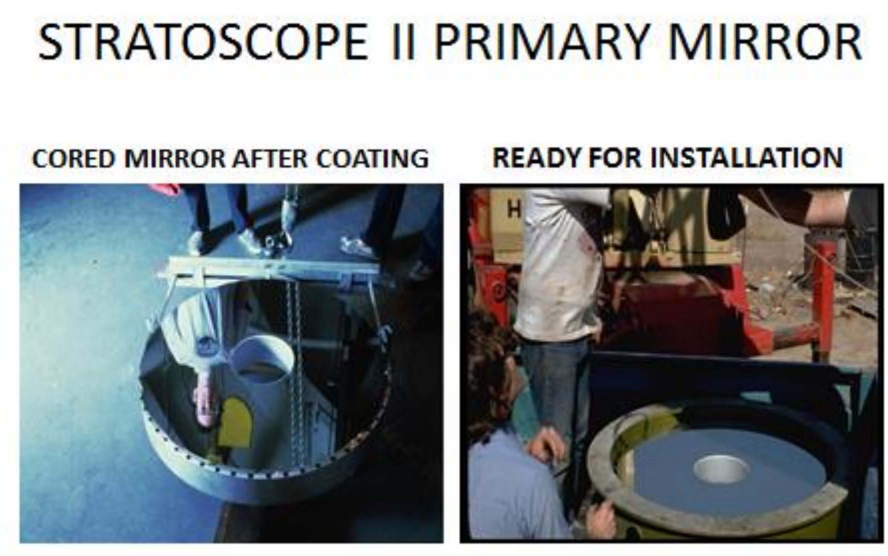

Currently, under the direction of Dr. Bruce Weaver, MIRA conducts world class research projects. The Observatory also offers public viewing on scheduled, dark-of-the-moon nights. These public nights include an invitation to families and ATMers to bring their personal telescopes and enjoy an evening Star Party.

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On a personal note, at my first visit to a MIRA Star Party, I became aware that with the nights as an ATMer, the lone Astronomy course that I taught at Monterey Peninsula College, and the mirror which consumed 2-1/2 years of my life, I had completed a career cycle!

In summary, the world of large optics testing underwent a paradigm shift as a result of the challenges presented by Stratoscope II. Not only did evaluation in vacuum tanks become the order of the day for space systems, but also, optical fabrication and testing evolved from 1859 knife-edge tests to the 1962 methods of interferometry. By the year 1967, the need to place perfect optical systems in orbit to conduct surveillance and reconnaissance of the Soviet empire would dominate the industry. All future space-certified systems would undergo interferometric evaluation in large vacuum chambers located around the country.

To recap the advances in optical testing made at P-E under Dr. Schwardzchild's sponsorship during the period June 1961 through January 1964, the following is offered as evidence:

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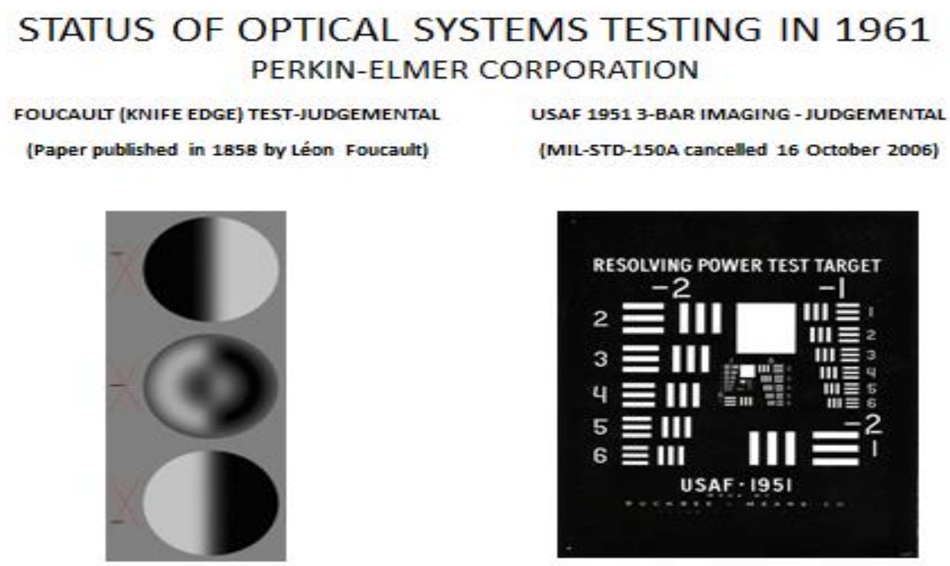
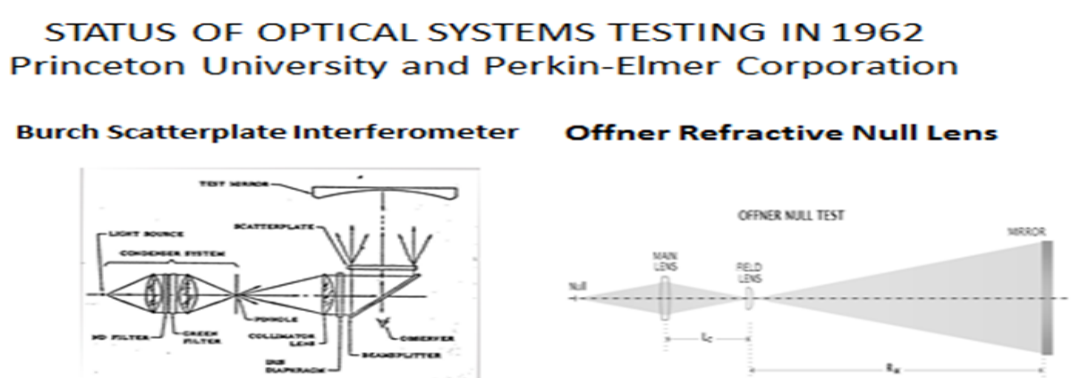
From the vintage, judgmental 1859 Foucault test for components and the subjective USAF 1951 3-bar target test in 1961………



……to quantitative, objective testing with a scatterplate interferometer and Offner Null Lens in 1962.



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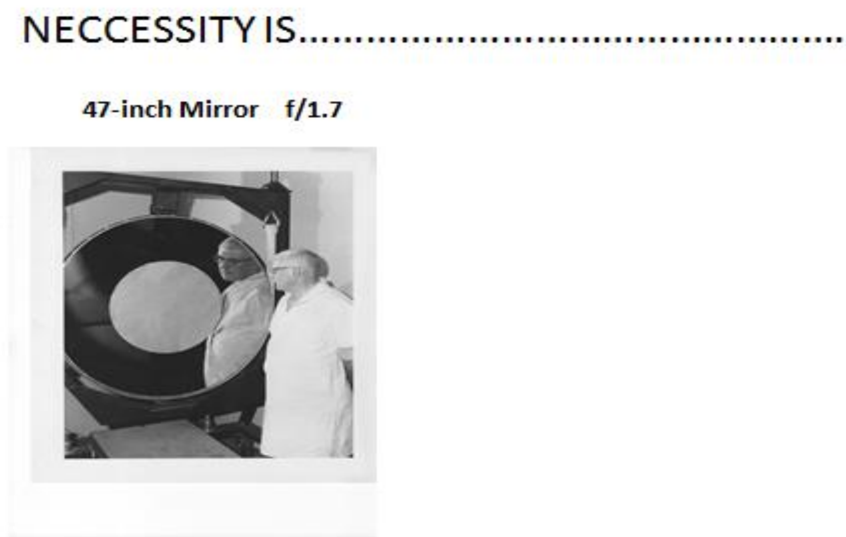

After the completion of the Stratoscope II mirrors, I joined Itek Corporation in January 1964. I realized that none of the P-E innovations in optical testing had spread to other parts of the community. Itek was still using the 1859 vintage knife-edge test to qualify optical components and the USAF 1951 3-bar targets to qualify optical systems.

I, at once, employed Scatterplate interferometry to solve fabrication and testing problems that were causing project budgets to be overrun and deliveries to fall behind schedule. In three months when all was going well……..there suddenly appeared this 47-inch metal monster with a central 26-inch hole. Oops! There would be no central surface area on which to put a scatterplate reference patch…….the patch that produced fringes in a scatterplate interferometer! Placing the patch on one side of the mirror, caused the interference fringes on the opposite side to be too faint to see.

My earlier experimentation with a ruby laser to produce fringes with two highly disparate paths indicated that it might be possible to augment a Twyman-Green configuration. Depending on the monochromaticity and strength of the light source, there should be interference fringes. Overnight it became obvious to me that a newly developed Perkin-Elmer, Helium-Neon gas laser, operating at 633 nanometer…in the visible red….would provide the perfect and least expensive solution.

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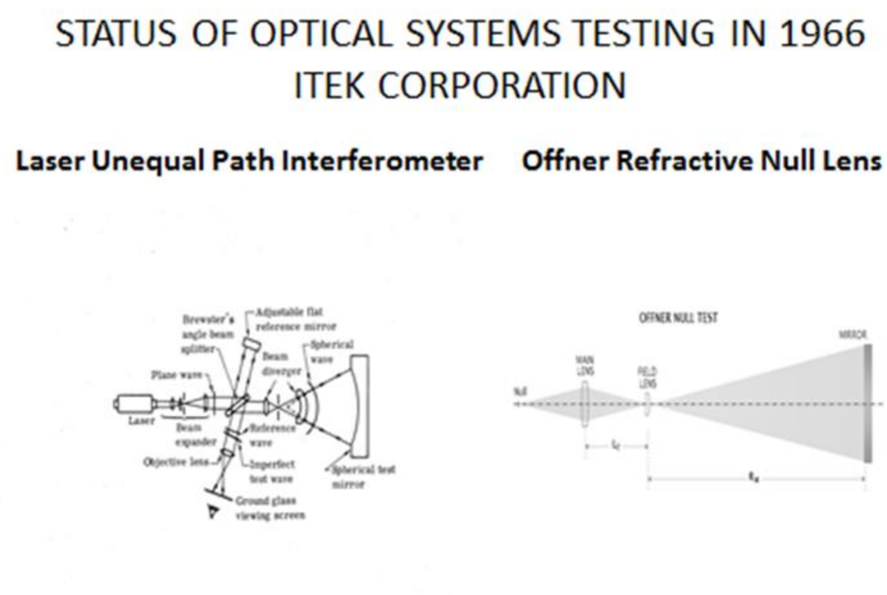

After selecting components and modifying the layout, this was my final configuration. See Applied Optics, 6/1237 (1967).

http://www.ncbi.nlm.nih.gov/pubmed/20062171

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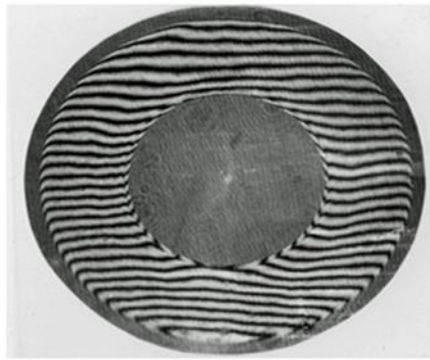
....THE MOTHER OF INVENTION



When the first Twyman-Green type fringes <u>with an equivalent path difference of many meters</u> were captured on Polaroid film, I filed a patent application. The application was for an ***appareil de mesure interferometrique*** or when translated to English, an interferometric measuring apparatus. At Itek it was named instantly, the LUPI….standing for laser unequal path interferometer, in order to distinguish it from other conventional instruments.

I am greatly indebted to Dr. Dow Smith, Vice-President and Chief Scientist and one of the founders of the Itek Corporation for his forbearance with "what I didn't know." As I experimented with the optimum design for a laser unequal path interferometer, Dr. Smith would shake his head and say, “but Joe, it goes against first principles in optics.” Then he would add, “I’m not getting it, but keep going.” Furthermore, he supported my belief that a gas laser would work in a Twyman-Green configuration. And it did!

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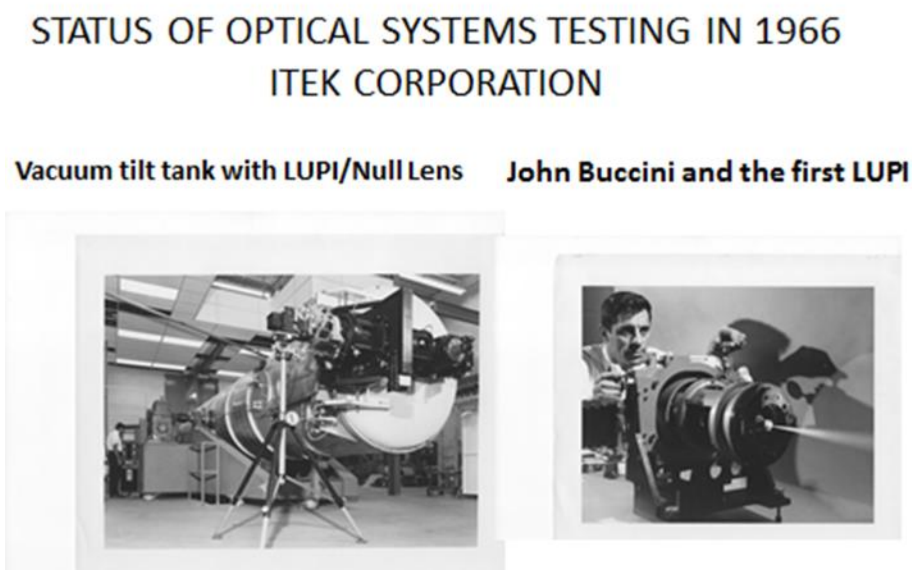

At the same time, I formed a test team consisting of John Buccini, a mechanical engineer with previous design experience at Winchester Arms, and Pat O’Neill, a lens designer with experience in shop techniques.

My colleague, John, used my original breadboard along with a set of design rules and a list of accessories to create an elegant instrument which could be mass produced and meet optical test requirements as follows:

NEXT SLIDE (TO BE READ)

LUPI PRODUCTION REQUIREMENTS

- \- Accommodate a wide range of f-numbers.
- \- Convert between f-numbers in a few minutes.
- \- Use 1-inch diameter reference flats.
- \- Vary flat reflectance from “anti” to 100%.
- \- Able to “tune” reference flat.
- \- Produce no artifacts or unwanted fringes.
- \- Be compatible with Foucault knife-edge tests.
- \- Work with null lenses and other tools.
- \- Perform in all physical orientations.

NEXT SLIDE (TO BE VIEWED – OR READ)

CAUTION

- LUPI INSTRUMENTATION IS NOT INTENDED TO REPLACE OTHER OPTICAL TEST METHODS SUCH AS STAR, FOUCAULT, GAVIOLA, RONCHI, HARTMANN, HOLOGRAPHIC, TIME TOOL OR OTHER TYPES OF INTERFEROMETERS.
- COMMON SENSE SHOULD DICTATE THE TYPE OF TESTING NEEDED TO CHARACTERIZE AN OPTICAL COMPONENT OR SYSTEM USING IN ALL CASES, THE MOST COST-EFFECTIVE APPROACH.

Later, optical engineers would place a “phase shifter”, i.e., a piezo operated flat, in front of the permanent reference flat. Pre-aligned custom computer-generated hologram (CGH) nulls for high accuracy figure metrology of deep aspherics were also added to the basic LUPI configuration. For example, an ad by SORL states that “software permitting mapping and averaging, wave-front scanning, fringe fitting, and subtraction of aberrations and polynomials” is available with the LUPI hardware.

Other optical instruments such as periscopes and space-based imaging systems would benefit from the innovation sponsored by Martin Schwarschild and Dow Smith.

The LUPI spawned an entire generation of unequal path interferometers. In the next section we address its legacy.

NEXT SLIDE (READ)

LEGACY OF THE LUPI

(Swiss Patent No. 463141 dated 15 Nov 1968)

- ZYGO CORPORATION INTRODUCED THE GH-1 (FIZEAU) LASER INTERFEROMETER IN 1972.
- ROLAND SHACK & GEORGE HOPKINS OF THE UNIVERSITY OF ARIZONA INTRODUCED THE SHACK INTERFEROMETER (SHACK CUBE) IN 1979.
- WYCO INTRODUCED THE WYCO 6000 (FIZEAU) INTERFEROMETER IN 1988.
- 4D VISION TECHNOLOGY INTRODUCED THE FIRST PhaseCam INTERFEROMETER IN 2000.

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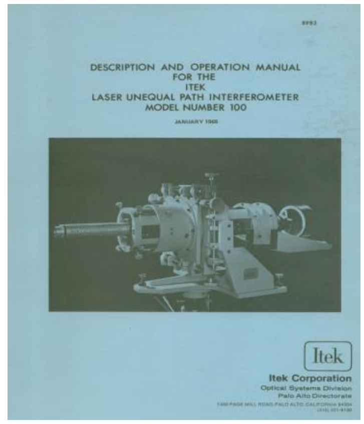
FIRST COMMERCIAL LUPI

JANUARY 1969

UNIVERSITY OF ARIZONA
MEINEL BUILDING

ITEK CORPORATION
MODEL 100



- The first commercially designed LUPI was delivered to Dr. Aden Meinel, Director of the Optical Sciences Center, University of Arizona, in the late 1960s.
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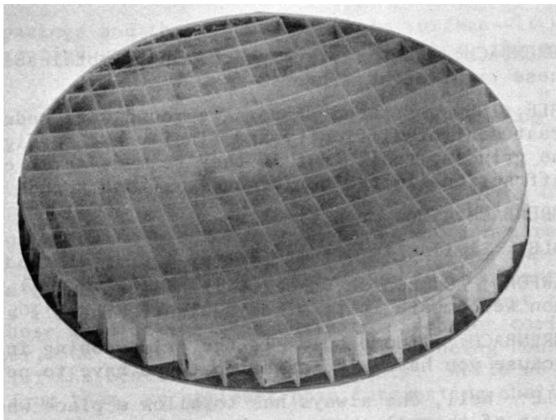
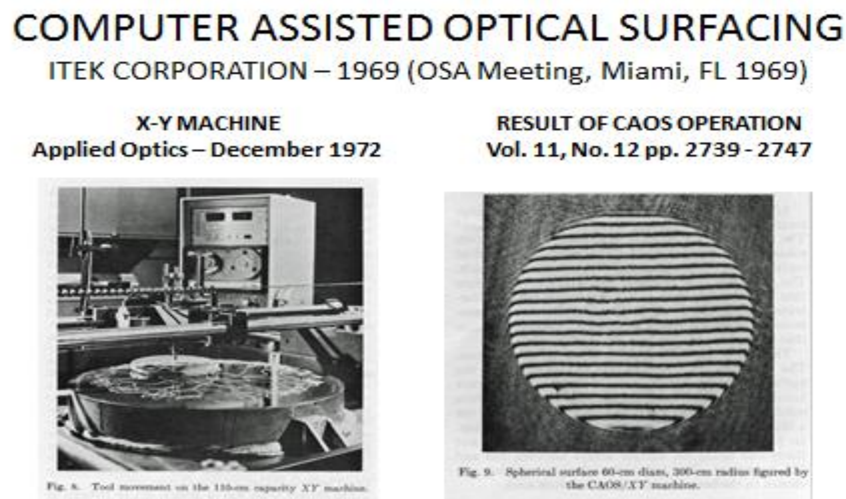
LIGHTWEIGHT MIRROR

- “Eggcrate” Design:



- LUPI testing in a large vacuum tank at Itek resulted in producing six 44-inch **light-weighted** (egg-crate style), high quality, aspheric mirrors at the rate of one per month.

NEXT SLIDE



- The LUPI generated digital topographic maps of optical surfaces enabled the development of computer assisted fabrication equipment and a host of software routines which provided for highly predictable outcomes of lens design tasks and optical systems analysis.

NEXT SLIDE

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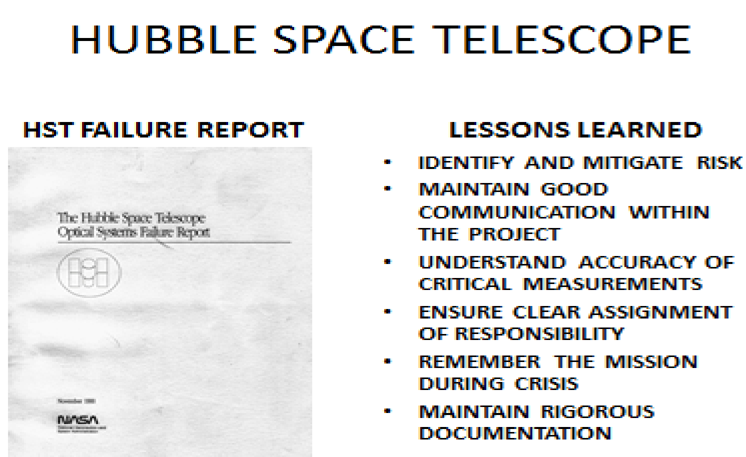
- Multiple LUPIs were delivered to the Perkin-Elmer Corporation in the late 1960s to enable the fabrication and testing of large space-based optical systems such as the recently declassified “Hexagon” KH-9 Reconnaissance Satellite and NASA’s Hubble Space Telescope.

NEXT SLIDE



- The LUPI was used to identify a catastrophic error caused by the improper use of an “innovative” version of a P-E null lens. This misuse resulted in a major setback in the HST project.

NEXT SLIDE

ASTRONAUT DR. KATHRYN C. THORNTON

- MISSION SPECIALIST “KT”

- STS-61 HST REPAIR MISSION

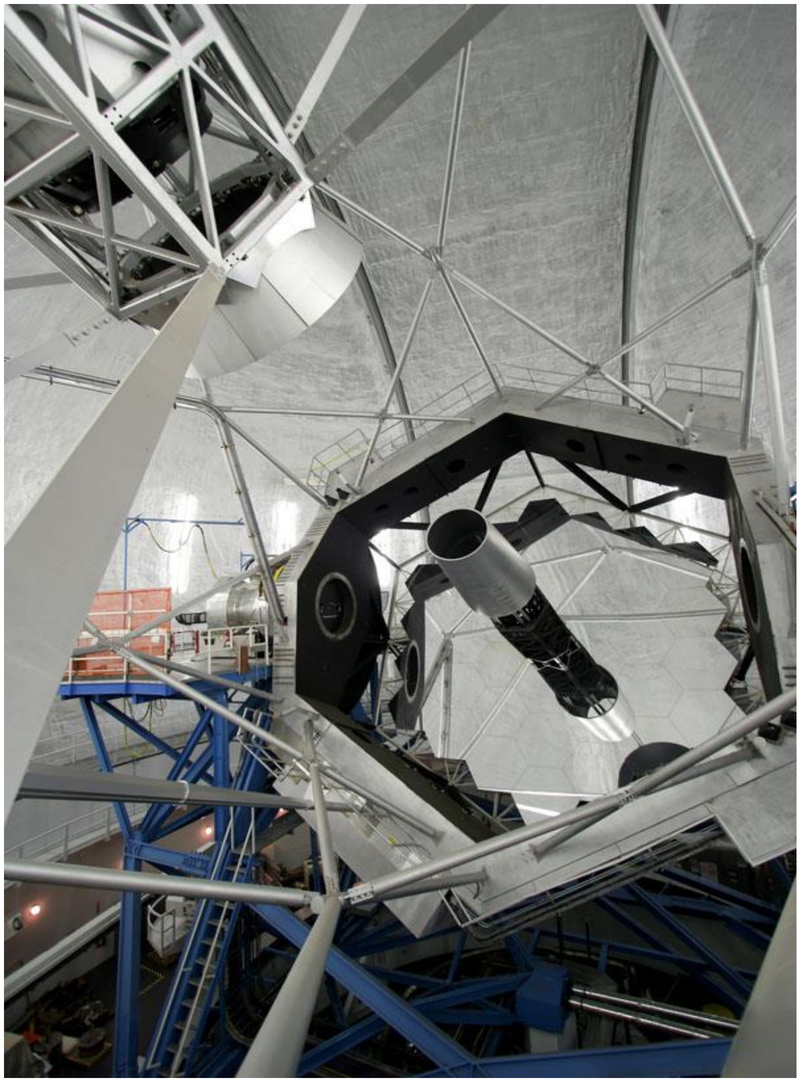
Corrective optics based on the LUPI data were installed in the orbiting HST by a mission specialist and colleague, Dr. Kathryn Thornton, and her team.

NEXT SLIDE

THE TIME TOOL

- Application of the LUPI with fielded systems, used in conjunction with the TIME Tool, allowed operators to ***quantify*** the performance of optical systems ***in situ***. Quantification permitted them to differentiate between wave-front errors caused by optical fabrication and testing errors and/or wave-front errors generated by misalignment; component mounting problems; thermal or atmospheric effects; or wear and tear on the equipment.

NEXT SLIDE

- 
- Utilizing several LUPIs simultaneously in the massive optics shop in Lexington, MA, the famous Keck telescope optical segments were completed by Itek in record time.

NEXT SLIDE

- Over 150 authentic LUPIs have been delivered by Buccini Instrument Company (BIC). Thirty three years later, BIC continues to deliver LUPIs world-wide.

With the geographic expansion of LUPI sales, an on-line and real-time training model for international use is in the development stages.

Footnote: Since almost anyone can build a LUPI from commercial parts these days (2014), there is no record of the total number of LUPIs in use. Example: Tinsley and SORL built and/or sold versions in the 1970s (and later) simply by re-packaging the original design.

OTHER INTERFEROMETER APPLICATIONS

There are a large number of telescope….and periscope…..projects both in astronomy and in the optics sector of the military-industrial complex that benefitted from these early days of experimentation. Here are three critical, "game changing" examples:

EXAMPLE #1:

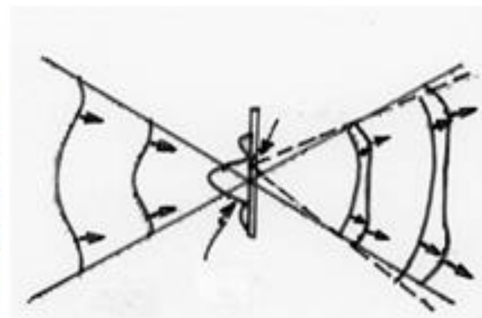
SUBMARINE PERISCOPE SURVEILLANCE

NEXT SLIDE

INTERFEROMETER TEST *IN SITU*

SUBMARINE BASE, GROTON, CT

HOW A PDI WORKS



In 1969 at Itek, I shifted from airborne and space reconnaissance optics to submarine periscope development, including sea trials in the Atlantic aboard the fast attack nuclear submarine USS Dace. The following year I designed an underwater lighting and camera system which enabled the CIA to raise a portion of a sunken Russian submarine from 3 miles below the Pacific Ocean's surface.

Based on those experiences, I accepted a position at Kollmorgen's Electro-Optics Division and became engaged in testing and selling American periscopes to the German Navy. Concurrently, I "moonlighted" for Dr. John Strong at the University of Massachusetts. Dr. Strong tasked me to evaluate the condition of student telescopes both at UMass and at Amherst College and suggest ways of restoring them to mint condition. During one of our meetings he introduced me to his graduate student, Ray Smartt, who had recently invented a Point Diffraction Interferometer (PDI). We discussed possibilities for using this new device to test optical instruments *in situ.*

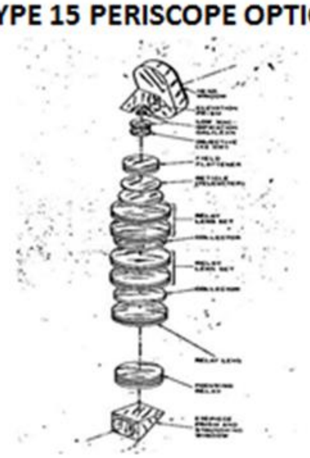
After successfully using the PDI in the Kollmorgen optics lab to characterize two catadioptric telescopes (a Questar and a Celestron), I arranged to test a conventional periscope installed on an operational nuclear submarine in Groton, CT.

The waterfront test on a very, very cold February evening was conducted over a distance of one-half mile between a helium-neon gas laser light source and the PDI-periscope eyepiece combination below deck. It was a total success. Now we could evaluate an installed and raised naval periscope in the “sail” shortly before deployment and ensure that the boat would get great pictures!

NEXT SLIDE

RESULTS OF TYPE 15 TEST

TYPE 15 PERISCOPE OPTICS



PDI INTERFEROGRAM

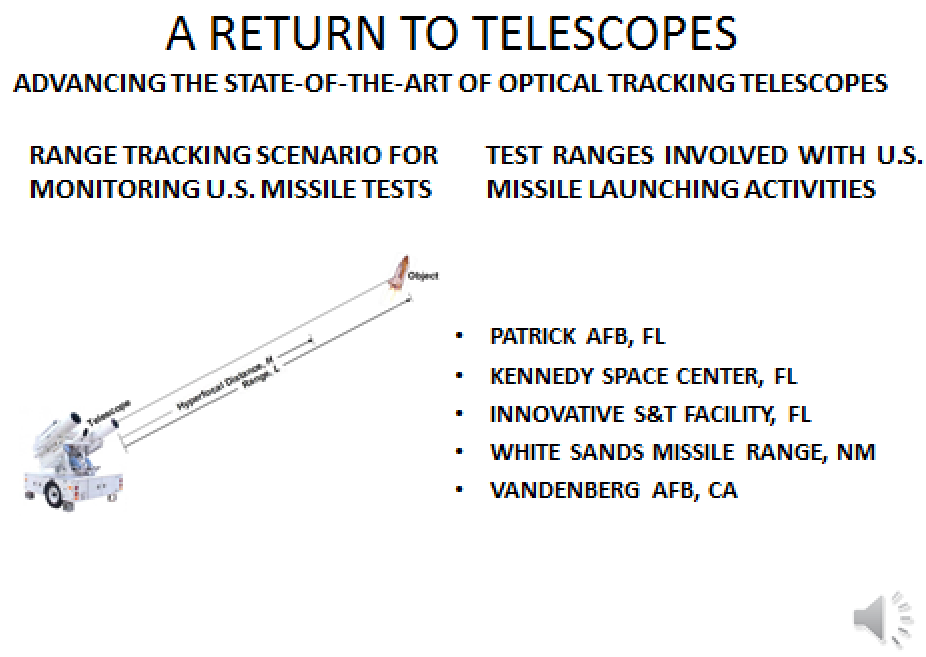
This demonstration firmly established the PDI as a "one pass" device to be used in the field. It is portable and easily adaptable for testing astronomical telescopes.

EXAMPLE #2:

OPTICAL TRACKING TELESCOPES

Since 1993 I have designed, built, tested, and in keeping with the times, recycled telescopes; as well as myself!

NEXT SLIDE



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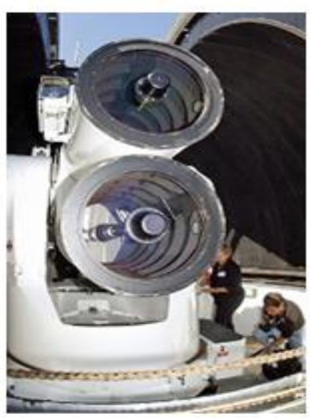
As we all too painfully remember, several tragic accidents occurred at the Kennedy Space Center in Florida during the Space Shuttle’s launch phase. The government lacked detailed, photographic evidence of the cause. At the time of these accidents, telescopes at the Cape were utilized without regard to their condition and/or capability. Test engineers and operators used outdated 1859 vintage knife-edge tests and/or 3-bar targets to certify performance and troubleshoot the telescopes. The U. S. Air Force enlisted my services to solve the problems. Using the LUPI, I first upgraded an old range telescope in six months and simultaneously established a range protocol for evaluating and maintaining equipment.

Based on this initial success, I undertook a series of telescope modifications and upgrades of a more recently acquired tracking telescope, known as DOAMS (Distant Object Attitude Measurement System).

NEXT SLIDE

DOAMS – PATRICK AFB, FLORIDA



I have two humorous anecdotes to illustrate the vast improvement achieved in optical performance

Telescope operators at Patrick Air Force Base are not expected to know about astronomical objects and sophisticated optical systems although they do use stars from time to time for aligning the two catadioptric telescopes that comprise the DOAMS configuration. After spending several months upgrading and realigning the optics, the telescope support and maintenance team received a frantic call from a tracking operator declaring, “you guys failed to do your job!”

NEXT SLIDE

It seems that when the operators pointed the telescope at Polaris….a routine operation to check the telescope's coordinate pointing software….the North Star (a point source) appeared to have a "companion" spurious reflection!?!? The team was directed to immediately take the DOAMS back to the laboratory and fix the problem.

Believe it or not, the operators had never realized that Polaris is a binary system!

My second anecdote deals with atmospheric turbulence which occurs during the summer months along Florida's beaches. This turbulence is especially severe during the summer months.

Not long after the first frantic call, the maintenance team received another; this time from the manager of the tracking site operators. He yelled, “you guys screwed up again with the optics…we’re getting a horrible case of focus flutter!” Immediately, dozens of tests were conducted by the maintenance team and the operators. Over a period of several weeks, it was observed that “focus flutter” first appeared late in the morning and dissipated by nightfall. It was also noted that it was worse when the telescope was pointed at the horizon! It took months to convince the manager and the operators that the phenomenon was simply a case of atmospheric turbulence…not bad optics.

Without the quantitative capability of interferometry, the U.S. Air Force might have spent a fortune troubleshooting telescopes while attempting to perform an impossible task of teaching practical optics and elementary astronomy to a group of tracking operators at the Cape. The operators were adamant that knowledge of optics and astronomy was not in their job description.

NEXT SLIDE

An example of raw power and the awesomeness of every lift-off event at the Cape, this image represents the “focus” of the DOAMS mission!

NEXT SLIDE

TRANQUILLON PEAK
VANDENBERG AFB, CALIFORNIA

Based on the enhanced capability of the optical tracking telescopes at Patrick AFB, two other national ranges elected to upgrade their DOAMS telescopes for operation in the infrared portion of the spectrum. These ranges included White Sands Missile Range, NM, and Vandenberg AFB, CA.

Yes, even telescope technology moved west (and I definitely wasn’t a young man).

NEXT SLIDE

Example #3

DOCUMENTING EVENTS IN THE STRATOSPHERE

Based on my experience at Patrick AFB, I consulted on Project STRATOS.

Project STRATOS was a project sponsored by the company who makes the energy drink "Red Bull." The purpose of this project was to understand what is required in technical innovation to bring astronauts safely to earth in the event of an emergency in orbit.

NEXT SLIDE

SHUTTLE COLUMBIA BREAKUP

The physician who led the medical team had lost his scientist/astronaut wife in the Shuttle Columbia breakup.

The commercial project required 4½ years and about $16 million to complete. One of the critical issues addressed during the first year of the project was the quality of the optical windows that would both protect the on-board cameras and allow for perfect imagery. Optical windows mounted in a housing to accommodate the temperature and near vacuum of space are expensive. The windows were fabricated and tested with an interferometer similar to the style I had used at Itek for building windows for the U-2 and other camera platforms. Month after month I reminded the project team that “if you don’t have high quality windows in order to visually record this very expensive, record-setting leap from space, it will have never happened!”

My seven decades in and out of range tracking optics usually found me watching objects leaving the earth’s surface and heading skyward. In this case, call it “reverse engineering,” the task was to track from near space to the ground.

NEXT SLIDE

STRATOS STANDUP LANDING

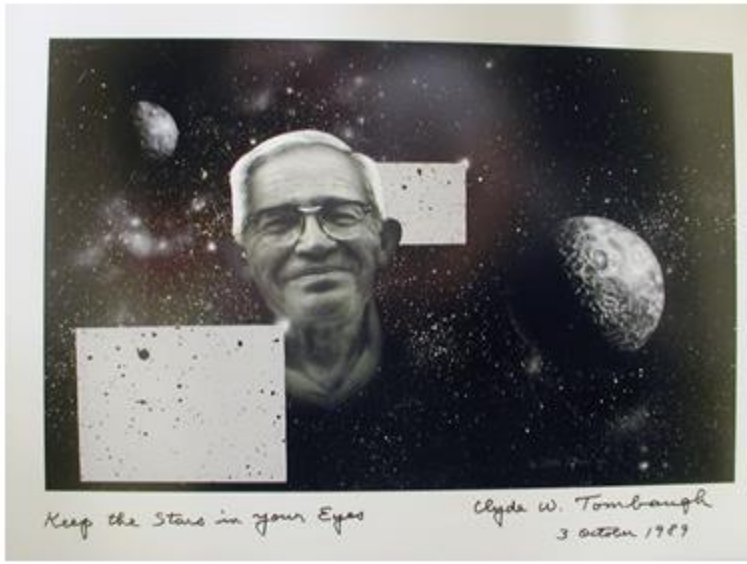
(14 OCT 2012 - NEAR ROSWELL, NM)

- FELIX BAUMGARTNER BREAKS THE SOUND BARRIER AND RETURNS SAFELY TO EARTH

After successfully completing his daredevil space-dive, landing safely in a field near Roswell, NM, Felix Baumgartner, who became the first human to break the sound barrier, said that his greatest fear was “messing up a stand-up landing and falling flat on his face in front of millions of viewers.” No doubt many of you witnessed this event live on TV and saw it on You Tube where it received millions of hits.

LAST SLIDE

"KEEP THE STARS IN YOUR EYES"



I had the unbelievable good fortune to meet the legendary ATMer, Clyde Tombaugh, the evening of February 6^{th}, 1980, in Las Cruces, NM on the occasion of his 74^{th} birthday and the celebration of the 50^{th} year since his famous discovery of the planet Pluto. His photo resides in my office as a reminder every day to "**keep the stars (especially the binaries) in your eyes**."

Again, thank you John for presenting on my behalf, this retrospective of my long association with astronomy and optics.

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