400 Years *of the* Telescope

A Journey of Science, Technology and Thought

A publication of the US IYA2009 Program

October 2008

Neil deGrasse Tyson lays down the narrative track at Skywalker Ranch

Production Update

"That's a wrap!"

By Kris Koenig, Producer

Ah, music to the ears of the field production team after spending three months of living and working on the road. The crew and I have logged over 45,000 air miles, several thousand car travel miles and dozens of hotel rooms. Each member of team has been separated from their friends and families, undergoing the pain of resetting their body's internal clocks to work around the dozens of time zones we found ourselves in. Each one sacrificed a lot to gather material that will produce a visually stunning and compelling documentary.

The past month we traveled to Mauna Kea on the island of Hawaii. At over 13,000 feet, this sacred mountain in the Hawaiian culture provides some of the finest conditions to place astronomical observatories. The steady flow of air across the Pacific creates some of the best "seeing" on the planet. That is why institutions from around the world have

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Engineering the "Light Bucket"

By Trudy E. Bell

The history of the astronomical telescope has moved in a baffling "seesaw" motion between lens-type and mirror-type instruments over the past several centuries.

In 1609, Galileo turned two small lenses mounted in a tube toward the heavens and made amazing discoveries about the solar system. By 1689, Sir Issac Newton assembled combinations of mirrors into a reflecting telescope design that is still in use today and known to us simply as the "Newtonian". In the 1770s, William Herschel built large reflecting telescopes, his biggest in 1787, with a mirror 4 feet across and a tube 40

The 100-inch Hooker reflector on Mt. Wilson in California led a revolution in the design and construction of large reflecting telescopes which continues today.

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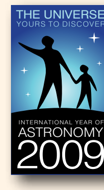

IYA2009 International Update

www.astronomy2009.org

Organisational Matters

The IYA2009 is still growing: we have 126 National Nodes and we would like to take this opportunity to welcome the Republic of Belarus and DPR Korea, our latest National Nodes, to IYA2009.

IYA2009 Questionnaire to SPoCs

We have received questionnaires

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US IYA2009 Update

NPR Discusses IYA2009 as Promotion Ramps Up

By Douglas Isbell

The U.S. project office for IYA2009 is beginning to ramp up our promotional efforts, as the national key projects and major events are starting to solidify. One recent highlight was discussion of the IYA2009 and the Galileoscope telescope kit on National Public Radio's (NPR) "Science Friday" program on September 19.

Host Ira Flatow was in Tucson to report on the latest findings from the Phoenix Mars Lander and wanted to spend a bit of time talking about the natural appeal of astronomy in Arizona. He invited US

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A technician inspects a 4-meter mirror substrate made of ZERODUR glass ceramic from SCHOTT AG in Mainz, Germany. The near zero-expansion material can be used in extreme operating temperatures without deviation in form, thus delivering crystal clear images for astronomical research. The material also demonstrates outstanding homogeneity, good chemical stability and can be precisely polished to meet the specifications for astronomical mirrors.

From Heidelberg to Hawaii

SCHOTT's Century of Astronomy

by Dr. Thorsten Doehring
Project Manager, Astronomy and Space Science, SCHOTT AG

Editor's Note: This month, "400 Years of the Telescope" recognizes the achievements of SCHOTT AG, one of astronomy's greatest pioneering glass manufacturers. Beginning over 100 years ago, SCHOTT's technological advancements have made possible some of the today's largest and most productive telescopes. A multinational, technology-based group headquartered in Germany, SCHOTT is celebrating the 40th anniversary of the company's introduction of ZERODUR glass, one of its many fine specialty materials. But the foundation and history of SCHOTT goes far beyond one product. By the dawn of the last century, the firm had already accumulated two decades of experience producing specialized glasses for scientific and industrial applications. Visit the company's website at www.schott.com to learn more.

In 1903 SCHOTT began its first century of work in astronomy. The company's first commission was for a telescope mirror from the State Observatory of the University of Heidelberg. SCHOTT produced a crown glass mirror substrate with a diameter of 720 millimeters (about 30 inches). Once the instrument became operational on Koenigsstuhl Mountain in 1906, astronomer Max Wolf rediscovered Halley's Comet and cataloged countless variable stars. With the addition of a spectrograph and modern CCD detectors, the Waltz reflector served for almost a century.

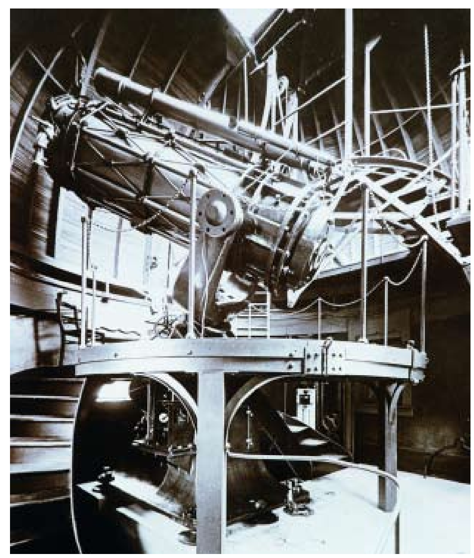
Later in that decade, SCHOTT produced a mirror substrate measuring 1.02 meters in diameter for Hamburg's Bergedorf Observatory. For many years one of the great 20th Century astronomers, Walter Baade, used this telescope for observations of nebulae and galaxies, and at one point tried to arrange to have it moved from Hamburg to a region of Germany with darker skies.

In 1920 SCHOTT began work on the Berlin-Babelsberg telescope and a mirror substrate with a diameter of 1.25 meters. When completed in 1924, it was the third largest telescope in the world behind the 60-inch and 100-inch reflectors on Mount Wilson near Los Angeles. This telescope made Babelsberg the best-equipped observatory in Europe. The instrument survived World War II, but in 1946 it was confiscated as war reparations by the Soviet Union. It was disassembled and transported to the Crimea, where it is still in operation.

With the war and its aftermath, development of large-scale astronomical equipment came to a standstill in Germany until 1948. In that year, the director of the Astrophysical Observatory in Potsdam, Professor Hans Kienle, filed an application for a two-meter telescope from the German Academy of the Sciences. Kienle's application read:

"A two-meter universal reflecting telescope is urgently required by the German astronomers in order to be able to return to the forefront of astronomical research with such a high-performance instrument. The construction of this telescope will at the same time provide effective proof of the efficiency of the 'Jenaer Werke' of Carl Zeiss and SCHOTT."

For this instrument SCHOTT used ZK 7 glass, a material with less than half the heat expansion of other crown glasses. SCHOTT produced a mirror blank with a diameter of 2.15 meters and weighing more than 3,000 kilograms. The two-meter telescope began operations in 1960 at the Thuringian State Observatory in Tautenburg near Jena.



The first mirror telescope of the University of Heidelberg began operations on the Königsstuhl in 1906. The mirror substrate from SCHOTT measured 720 mm.

By the early 1960s, it became clear that a new generation of great telescopes would

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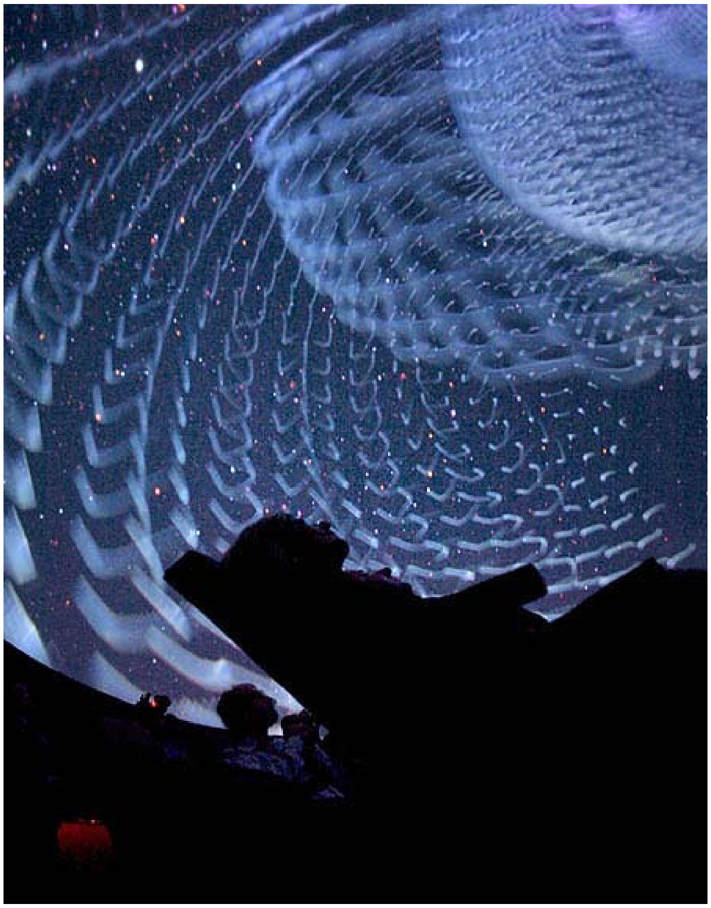

Buhl visitors enjoying a full-dome immersive experience

Welcome!

"400 Years of the Telescope" Welcomes the Buhl Planetarium

By Dan Malerbo
Education Coordinator, Henry Buhl Jr. Planetarium & Observatory

The Buhl Planetarium and Institute of Popular Science opened in October 1939 on the north side of Pittsburgh. Buhl was the fifth major planetarium in the United States and joined the Adler Planetarium in Chicago, the Hayden Planetarium in New York, the Griffith Observatory and Planetarium in Los Angeles, and the Fels Planetarium at the Franklin Institute in Philadelphia. The original Buhl Planetarium, featuring a 492-seat "Theater of the Stars" under a 65-foot diameter dome, was built with a donation of $1.1 million from the Buhl Foundation, established by a bequest from the estate of north side businessman Henry Buhl.

In its first full year of operation in 1940, over 200,000 people visited the planetarium to gaze at the night skies produced by the Zeiss Model II electro-mechanical projector, which rose dramatically out of the floor for each performance, to the excitement of each audience member. On the planetarium's roof, a siderostat telescope allowed visitors to follow stars and planets across the night sky. It was the first such telescope designed for public education, rather than for astronomical research. Hundreds of thousands of Pittsburgh residents and their guests still fondly remember trips to the Buhl Planetarium in the 1940s through the 1980s.

In 1982 the Buhl Planetarium became the Buhl Science Center and plans were made to relocate the facility to land on the Ohio River, just below the Pittsburgh Pirate's new home at Heinz Field. In 1987, the Buhl Science Center merged with Carnegie Museums of Pittsburgh, and five years later, in October 1991, the new Henry Buhl, Jr. Planetarium & Observatory opened in the newly established Carnegie Science Center.

The new Buhl facility continues to be underwritten by the Buhl Foundation. It has served as a state-of-the-art facility and a model for planetariums around the world. Today, with 150 seats and a 50-foot dome, it is considered one of the most technically sophisticated planetariums of the approximately 3,000 facilities worldwide. It is one of only a few dozen with interactive capabilities. Sophisticated "flight controllers"—an interactive system mounted in every seat armrest in the theater allowing members of the audience the ability to focus on a particular area of the screen and manipulate the direction a program takes in real time. Participants can pan an image either left or right, or change the pace of the show. Show participants, through "majority vote" using their flight controllers, determine what the entire audience will experience.

The Buhl Planetarium has established itself internationally as a leading designer of quality planetarium programs with innovative content. The planetarium has distributed more than 400 shows in the United States and on four other continents. Buhl shows have been translated into 18 languages. Buhl Planetarium productions are so highly regarded, that they have attracted the talents of futurist and science-fiction author Sir Arthur C. Clarke, who narrated *New Cosmos* and actor Leonard Nimoy, who lent his talents to the show "*The Search for Life in the Universe*". The Buhl has collaborated on projects with NASA, the Hubble Space Telescope Science Institute, The Center for Light Microscope Imaging and Biotechnology, Pittsburgh Tissue Engineering Initiative (PTEI), and Family Communications (producer of the very popular "Mister Rogers'

Carnegie Science Center, home of the Buhl Planetarium and Observatory

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Wrap! continued from page 1

established collaborations to build an unrivaled suite of observatories on this volcanic mountain. It's always a thrill for me to photograph and film at the summit.

Even though we had all worked at high altitudes throughout our recent travels, functioning at the top of Mauna Kea required the crew to work hard at staying focused. Lack of oxygen and a build up of CO_2 in the body from even the lightest of tasks stresses the human respiratory system. To overcome this effect, crew members learned "force breathing", a process of creating backpressure while slowing exhalation. Once they mastered the technique, crew members worked for several hours at a time at altitude with little problem. Everyone's acclimation to the summit's height over 14,000 feet was also helped by eating and sleeping at the support station's lower altitude of 10,000 feet.

We filmed over five days, recording the sights and sounds of the summit including the Canada-France-Hawaii Telescope, CalTech's Submillimeter Observatory, the W.M. Keck twin telescopes, the Smithsonian Submillimeter Array, Japan's Subaru Telescope, and the Gemini North Telescope. We had a great interview with Dr. Rolf Kudritzki, Director of the Institution of Astronomy at University of Hawaii, and we met Curtis Wong of Microsoft Research, who heads the Worldwide Telescope Project, **www.worldwidetelescope.org**. This is an incredible virtual online observatory that puts data of the world's great observatories at your fingertips. I highly recommend that you download the free application from their website and experience the future of astronomy. Currently, the application is only available for MS Windows systems. For you Mac OS X users, it's the only program I have seen worth partitioning your drive and loading Windows for. I give it five stars out of five rating!

Dr. Wendy Freedman avoids getting hit (this time) by production assistant Anita Ingrao's boom mic.

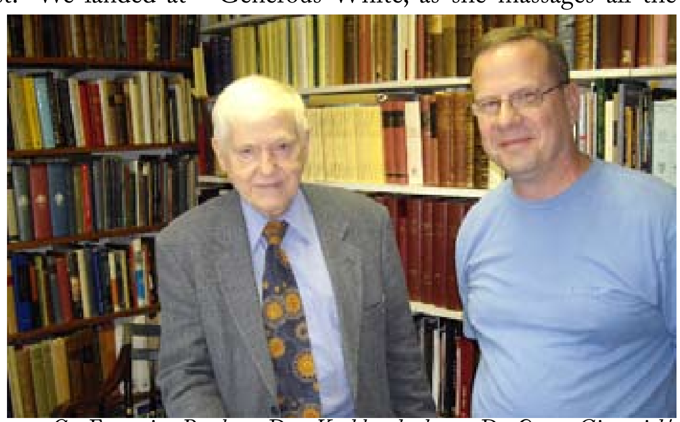
Once we returned from the Big Island we headed to the East Coast. We landed at Washington, DC, and drove to Green Bank, West Virginia to capture footage of the largest radio telescope. The Green Bank Radio Telescope, GBT, is a sight to behold. When its overwhelming structure is in motion, your mind has a hard time comprehending what it's seeing. Make sure you put a trip to Green Bank on your life experiences. When you're there, stop by Ryder's gas station and restaurant for a meal - great food at great prices. The service is a pleasurable experience, too.

We then headed to Hubble Space Telescope Science Institute in Baltimore. Here we interviewed Adam Reiss, a co-discoverer of Dark Energy. Adam is a very humble man and a delight to interview. The day we were there, the MacArthur Foundation named him one of their 2008 Fellows, an honor he truly deserves.

Our last East Coast stop, and our final interview for the documentary, was at the Harvard College Observatory in Cambridge, Massachusetts, with Dr. Owen Gingerich. Dr. Gingerich is the iconic astronomer and historian; he holds a lifetime of astronomical research behind his twinkling eyes that have read every early manuscript written on the heavens. My visits with him are always enlightening, yet too short.

With the filming finished, our next task was to record the narration. Dr. Neil DeGrasse Tyson, Director of the Hayden Planetarium in New York City, boarded a west-bound flight and joined us at George Lucas' famous Skywalker Ranch to record his unmatched voice of elegant authority on astronomy. The combination of one of the world's best recording environments with the silky-smooth pipes of Neil generated the audio backbone of the documentary, linking the interviews and the imagery together with words of the writers.

Over the next month we will be buried in the studio, assisting our editor Kimberly Generous White, as she massages all the elements gathered over the past eighteen months into a "rough-cut". Once this is done, Mark Slater, our composer will draft the score that will be played by the London Symphony Orchestra at Abbey Road Studios.



Co-Executive Producer Dan Koehler checks out Dr. Owen Gingerich's astronomical archives

The final program master is within sight!

Light Bucket *continued from page 1*

feet long. He used them to discover Uranus and other stellar wonders. But in the early nineteenth century most astronomers returned to building telescopes with small lenses. By 1897 the grandest telescope in existence was a refractor featuring a lens more than a yard across. Before the turn of the twentieth century, astronomers seeking bigger telescopes were abandoning lenses once again to embrace mirrors.

Why couldn't astronomers pick one design of telescope and stick with it?

In a word: engineering. Telescope design was influenced by what astronomers needed, and by what engineering technology could deliver. Astronomers desired ever-bigger aperture. A telescope is a light bucket. The bigger the bucket—the diameter of the lens or mirror—the more light it can gather, detecting faint and distant objects resolving detail better than a telescope with a small aperture.

Making a telescope with large aperture depended on the expertise of opticians fashioning the figure (curves) on the lens or mirror to focus starlight, as well as what was possible in fundamental technologies: casting of large disks of metal or glass, making structural steel (as opposed to cast iron), applying reflective coatings, wiring electric motors and controls, and much else.

Simple Lenses to Metal Mirrors

Galileo's first telescope consisted of two small lenses: a larger objective lens, which focused an image of a celestial object, and a smaller eyepiece lens that magnified that image. His lens consisted of a single piece of glass, flat on one side and convex on the other.

But a single lens acts as a prism, breaking light into a spectrum of color. When Galileo looked through his telescope, every star and planet was surrounded by rainbow fringes.

This problem, called "chromatic aberration", inspired Newton to devise reflecting telescopes, because, he discovered, mirrors equally reflect all colors of light.

Newton invented his reflector two centuries before the practice of coating glass with reflective metal. Eighteenth- and early nineteenth-century mirrors were made of speculum metal, a rather brittle compound of copper and tin with a dash of arsenic to turn it white. When the surface was polished smooth, it reflected a bright image.

William Herschel realized that speculum metal would allow him to make gigantic telescope mirrors. He set up factories for melting and casting solid disks of speculum metal, building machines for grinding the mirrors to the proper curve, and polishing them to a brilliant surface. His largest reflector had a mirror 4 feet across in a tube 40 feet long. In the nineteenth century, William Parsons, third Earl of Rosse, built the world's largest speculum reflector with a 6-foot metal mirror weighing 4 tons.

But both Herschel and Lord Rosse bumped against the limits of contemporary technology. In the damp English air, speculum metal tarnished. The massive mirrors became so dark and dull that every few months they had to be removed for re-polishing. As air temperature dropped after sunset, the mirrors contracted and changed optical figure, affecting their focus.

Metal-mirror reflectors had reached their practical limits.

Metal Mirrors to Achromatic Lenses

In the 1720s, opticians discovered that when a refracting telescope was made with two lenses of different kinds of glass, most of the color fringes disappeared. In the 1750s, British lens-maker John Dollond and his son Peter worked out a practical design for commercial astronomical telescopes by combining a lens of crown glass (plate or window glass) and one of flint glass (lead crystal). Such lens "doublets" came to be called achromatic (color-free).

The aperture of achromatic refractors was limited because the Dollonds used English flint glass, in which disks larger than 4 - 6 inches were streaked with veins, bubbles, and other imperfections. In the 1780s, Swiss glassmaker Pierre Louis Guinand developed a technique for stirring molten glass, devising the modern method of making large optical blanks by pressing a softened disk of homogeneous glass into a circular mold. This allowed him to produce flawless disks of flint glass up to 18 inches in diameter.

Guinand passed his glassmaking secrets to young Joseph Fraunhofer, who also computed curves for achromatic lenses. Fraunhofer cast, ground, and polished lenses for some of the finest refractors of the early nineteenth century; his 9-1/2-inch refractor at the Dorpat Observatory was for two decades the largest refractor in the world. Fraunhofer also invented the equatorial or "German" telescope mount with which a celestial object could be readily found using setting circles, and a "clock drive" employed to track its apparent movement across the sky due to Earth's rotation.

With these optical and engineering advances, the achromatic refractor was now the design of choice throughout the nineteenth century. Gigantic refractors were made possible by the optical skill of the greatest lens opticians of all time, the American firm of Alvan Clark and Sons. The Clarks figured optics for the world's largest refractors five times over, culminating with the 36-inch at Lick Observatory in California (1888) and the 40-inch at Yerkes Observatory in Wisconsin (1897).

Engineering played an equal role. Glassmakers Chance Bros., Feil & Co., and Mantois, cast optically perfect glass disks of ever larger diameters: 18-1/2, 26, 36, and 40 inches. Also, the metallurgical and mechanical skills of the engineering firm Warner & Swasey made possible the massive tubes, mountings, counterweights, clock drives, domes and movable floors needed to properly house and operate the new, large-lens telescopes. For the Lick 36-inch refractor on Mt. Hamilton near San Jose, California, Warner & Swasey pioneered the use of steel for the telescope's tube and mount. Of equal importance, the company's engineers devised mathematical formulas so they could accurately account for load and flexure of the mount and tube in all observing positions. This refinement in design was essential for the precise motion control of telescopes that eventually

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IYA *continued from page 1*

from most of you, and are now processing the data before a short report will be produced. Thank you very much to all of you who have sent the questionnaire.

IYA2009 New Website

After weeks of hard work the astronomy2009.org website has undergone an overhaul and now boasts improved design, functionality, navigation and resources! Receiving over 1500 visitors every day, it is gaining popularity and we are sure that this number will grow with time. More user-friendly than ever, the site provides an easy way to keep in touch with IYA2009 developments. We are always eager for your feedback, so please feel free to e-mail us at **iya2009@eso.org** with any suggestions. I would like to express my gratitude to the IYA2009 and ESA/Hubble team for the hard work! Please note that now you can't update your National page, so if you need to update your contact details, please send us an e-mail. It's our hope that all the National Nodes will have a National web page before the end of the year.

IYA2009 Resources

On the IYA2009 website you can find various resources that will help you promote IYA2009 in your community: **http://www.astronomy2009.org/resources/**

IYA2009 Cornerstone Projects

100 Hours of Astronomy:

The 100 Hours of Astronomy global Cornerstone project has created a mailing list that will be used to keep everyone informed of plans and news. If you want to know the latest on what is happening with this major event in IYA2009, sign up for this free service on the 100 Hours of Astronomy website at **www.100hoursofastronomy.org**.

Universe Awareness:

International News:

- The world of UNAWE
- Visits to the website
- New tools website
- Presenting UNAWE
- Other resources

Country News:

- India - Netherlands
- Skies above China - UNAWE Italy
- Cuentos de Estrellas - a Book by UNAWE en Español
- Giant astronomy games in Indonesia
- A Cartoon in Tunisia
- A Planetarium for Venezuela
- UNAWE Ireland is taking off

Download the PDF newsletter here: **http://tinyurl.com/unawe-news-Sept2008**

Upcoming IYA2009 meetings

IYA2009 Opening Event
15-16 January 2008
http://www.astronomy2009.fr/opening

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Report from European Planetary Science Congress Session: International Year of Astronomy 2009

Europlanet's European Planetary Science Congress, held this year in Munster, Germany, offered informative sessions on public engagement. The session "Outreach and Amateur Astronomy" was dedicated to IYA2009 talks. Read the full report from Lee Pullen on the IYA2009 website:

http://www.astronomy2009.org/resources/documents/detail/iya2009_epsc_report_lp/

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IYA2009 Single-Point-of-Contact Doug Isbell on the show, along with Adam Block of the University of Arizona's Mount Lemon SkyCenter, to talk about public outreach at Kitt Peak National Observatory, dark skies issues, and what's ahead for IYA2009.

Although the 17-minute segment was fairly brief, there was obvious interest in the Galileoscope IYA2009 cornerstone project, and what it can do to bring the wonders of the night sky to new audiences, so that everyone can "do what Galileo did." GLOBE at Night and related star-counting activities were also discussed. More than two dozen inquiries and other messages of support have been received since the program aired.

See **here** for some information on the show and some related links and **here** for a link to the podcast of the episode, which can be downloaded to your favorite mp3 file player.

The **US IYA2009 website** received a major design upgrade recently to better match the new **international site** and to turn its focus from the planning effort to more direct support for public information and events. Check it out, and help us add content, images, and details about your plans for the year!

Finally, plans are shaping up for a U.S. IYA2009 opening event on Tuesday evening, January 6, at the American Astronomical Society winter meeting in Long Beach, CA, including the world premiere of "400 Years of the Telescope." Watch this space for more details.

The second prototype of the Galileoscope telescope kit, which includes a mounting point for a standard camera tripod and small "legs" to keep it upright during assembly for use as an optical bench for hands-on optics educational exercises.

SCHOTT *continued from page 2*

require astronomical mirrors with even lower thermal expansion coefficients than ZK 7. The next step forward was Duran borosilicate glass mirror substrates with diameters of between one and two meters. The largest Egyptian telescope in Heluan was equipped with a 1.95-meter Duran mirror. The European Southern Observatory (ESO) still gets excellent images from a 1.6 meter reflector with a Duran mirror in Chile. The largest Duran disk, with a diameter of 2.7 meters, was cast in 1963. The casting process lasted several hours and the six-month cooling process took place in a specially built annealing furnace.

But the biggest milestone was the development in 1968 of ZERODUR glass ceramic, under the leadership of Dr. Juergen Petzold. ZERODUR's most important property is zero thermal expansion, crucial for images free of distortions. This glass ceramic is a lithium aluminium silicate, a hybrid made of glass and ceramic. In manufacturing this material, a specialized glass is initially poured and then tiny crystal seeds are created inside of it. The final glass ceramic consists of approximately 70 percent nanocrystallites, which exhibit negative thermal expansion, and a 30 percent share of glass. Both the number and the size of the crystallites are manipulated during manufacturing to ensure that the resulting material has a linear coefficient of thermal expansion that approaches zero. ZERODUR expansion is 1,000 times lower than that of aluminium, for example. Using specialized manufacturing techniques, it can be produced in large dimensions almost completely free from bubbles and inclusions, making it perfectly suited for the polishing that finishes telescope mirrors.

The first large-scale ZERODUR astronomy project was ordered in 1968 by the Max Planck Institute for Astronomy (MPIA) of Heidelberg. SCHOTT produced mirror substrates of 2.3 and 3.6 meters for the German-Spanish Calar Alto Observatory in Southern Spain. Until 1980, ZERODUR reflectors were built in the conventional, stable and massive form. These mirrors usually had a ratio of diameter to thickness of 6:1.

The New Technology Telescope (NTT) at the European Southern Observatory (ESO) in La Silla, Chile, was a different kind of milestone for SCHOTT. Installed in 1989, this telescope became the first to use a thin, actively bendable mirror to compensate for the shimmering in the earth's atmosphere. This shimmering is what causes the stars to twinkle and astronomical photography to blur.

Casting of a 4 meter telescope mirror at SCHOTT made of ZERODUR glass ceramic at SCHOTT in Mainz. The casting has a temperature of over 1,000 degrees Celsius.

The Very Large Telescope (VLT) array operated by ESO in Chile's Atacama Desert took mirrors to their limits with four substrates 8.2 meters in diameter. For this project, SCHOTT developed a novel centrifugal casting process in which the casting mold has a curved bottom and constantly rotates. In 1993 it delivered its first 8.2-meter mirror substrate. One substrate was supplied each year for the following three years.

While the four VLTs are among the most productive telescopes on Earth, it was not easy to cast what, by diameter, were the largest monolithic pieces of glass ever produced. Both astronomers and glass manufacturers concluded that they had definitely reached the limits for monolithic mirrors.

But demand for bigger apertures continued to grow. That led to the development of segmented mirrors consisting of hexagons formed into a single mirror. Here, the two Keck Telescopes, operating since 1992 and 1996 in Hawaii, were major breakthroughs, proving that segmented mirrors could work as well in practice as in theory. The two 10-meter mirrors each consist of 36 ZERODUR segments. In fact, of the 14 largest telescopes in the world, eight employ ZERODUR mirrors. These include the just-completed Gran Telescopio Canarias (GTC) in the Canary Islands, the two Keck telescopes in Hawaii, the Hobby-Eberly Telescope (HET) in Texas, and the four ESO Very Large Telescopes (VLT) in Chile.

But as big as the Kecks and the GTC are, two major projects will dwarf them. The Thirty Meter Telescope (TMT) in the United States will receive a mirror with a diameter of 30 meters and consisting of nearly 500 mirror segments. The European Extremely Large Telescope (E-ELT) planned by ESO for first light in 2017, will have a mirror 42 meters in diameter with 900 hexagonal segments. This will make the E-ELT the world's largest optical telescope.

Although the great telescopes draw the most attention, ZERODUR has played a critical role in smaller instruments used on aircraft and spacecraft. The SOFIA airborne observatory -- a Boeing 747 operated by NASA and the German Aerospace Center (DLR) -- carries a 2.5 meter telescope, the largest telescope ever mounted in an aircraft. Undergoing final tests in California, this telescope will become operational in 2009. Some of the most spectacular and detailed photographs of Mars are now being taken by the HiRISE camera on the Mars Reconnaissance Orbiter. These include portraits of the rovers riding on the Martian surface and the Phoenix Mars Lander descending by parachute to the Martian polar region.

As SCHOTT enters its second century producing mirrors for some of the world's largest telescopes, it is safe to say that both the biggest and best telescopes are yet to come.

Bucket continued from page 5

reached five to six stories in height, with moving masses comparable to that of the era's drawbridges.

With the 40-inch Yerkes refractor, large lenses effectively reached their technological limits. To minimize weight and light loss due to absorption by the lenses, the doublet was made as thin as possible. At their centers, the Yerkes crown glass is only 2.5 inches thick, and the flint glass is an even thinner 1.5 inches. Yet, the quarter-ton doublet, supported by only its periphery, sags slightly under its own weight at different observing positions. Lenses larger than the Yerkes doublet needed to be thicker, absorbing some of the starlight passing through them. Casting ever larger, optically perfect glass proved to be a monumental task. After a few attempts, the French firm of Mantois abandoned efforts to cast a doublet 52 inches in diameter in the years following their success with the Yerkes 40-inch glasses.

The era of giant refractors ended for good in June 1897 with the death of Alvan Clark's last son, Alvan G. Clark. The Clark firm's successors continued to build precision refractive optics for another half century. But, astronomer's needs, and their preferred telescopes, moved in a different direction yet again.

Achromatic Lenses to Glass Mirrors

European opticians experimented with coating glass—even telescope mirrors—with an ultrathin layer of silver, using risky, unreliable chemistry that required heating that often broke the glass. Although silver tarnished, it started out far more reflective than speculum metal. In 1862, New York science professor Henry Draper completed a 15-1/2-inch silver-on-glass reflecting telescope, with which he took stunning, detailed photographs of the Moon. His work introduced silver-on-glass mirrors to American astronomers. But the real enabling technology was the invention in 1880 of a cheap, simple and reliable silver-deposition process by the American optician John A Brashear – a technique that was used into the mid-twentieth century.

Silver-on-glass mirrors opened the way for the giant reflectors of the twentieth century. The silver coating was easily replaced when tarnished, and the glass did not need to be re-polished. Glass disks cast for reflectors do not require the same optical purity as refractors, because starlight "bounces" off the front surface of a mirror rather than being passed through a lens. Grinding, polishing and figuring the single front surface of a mirror is easier than figuring the four lens surfaces comprising an achromatic refractor. Big mirrors are easier to mount than big lenses because a telescope mirror is supported on both its edge and backside. Lenses can only be supported on their edge so starlight can pass through. Glass is less dense than speculum metal, making for a lighter-weight telescope and mount. In the late nineteenth century, with aperture being equal, a silver-on-glass reflector cost a fraction of either a lens-type or a speculum mirror telescope.

In 1895, Lick Observatory acquired its 36-inch silver-on-glass Crossley reflector, which became America's first large reflecting telescope. The success of the 36-inch Crossley reflector gave glassmakers, opticians and astronomers alike the confidence to manufacture increasingly larger mirror-type telescopes. St. Gobain Glassworks in Paris cast a glass disk 60 inches across, which was ground and polished by George W. Ritchey and installed on Mount Wilson in 1908. A few years later, St. Gobain cast a disk 8-1/3 feet across for the 100-inch Hooker reflector on Mt. Wilson, which, after its completion in 1917, remained the world's largest and most productive telescope for three decades.

But the 100-inch also reached the limit of silver-on-glass mirrors. Its glass expanded in the warmth of day and contracted in the cool of night, changing the mirror's optical figure. The task of dismounting and re-silvering the 4.5-ton 100-inch mirror every few months when its surface tarnished was monumental.

Telescope engineering advanced in the 1930s on several fronts. Corning Glass Works developed a heat-resistant borosilicate glass, called Pyrex, with a lower coefficient of thermal expansion that lessened the image distortion effects of temperature changes on glass. To reduce mass and increase the strength of a large Pyrex mirror, Corning engineers decided to use a ribbed or honeycomb structure on the backside. Variations of their original ribbed design are still used with large telescope mirrors today. John D. Strong developed a method of vaporizing a thin coating of aluminum on the front surface of a telescope mirror. Aluminum is almost as reflective as silver, it is more durable, and it doesn't tarnish. Mirrors are still aluminized today using the Strong process. Once combined, these three technological innovations made possible the massive 200-inch (or five meter) Hale telescope on Mt. Palomar, which was completed in 1948. It reigned as the world's largest until the 1970s.

Engineering Telescopes Today—and Tomorrow

With the development of laser-collimating systems, data-handling, and adaptive optics, telescopes today have apertures of 10 meters, made of a mosaic of thin mirror segments, reducing weight, cost, and thermal-settling time. These monster optics have abandoned Fraunhofer's equatorial mount and returned to Herschel's style of moving the telescope in altitude and azimuth.

The next generation of large reflectors may take advantage of a 150-year-old idea made feasible by engineering: a spinning liquid mirror up to 30 meters—nearly 100 feet—across, cradled in a motionless mount, steered exclusively by electronic wizardry.

Editor's Note: See "SCHOTT's Century of Astronomy" on page 2 of this issue to learn more about the history of telescope mirror manufacturing advances that have made possible the huge and sophisticated instruments used worldwide today.

Science journalist Trudy E. Bell, whose master's degree in the history of science is from New York University, is a former editor for Scientific American and IEEE Spectrum magazines. Winner of the American Astronomical Society's 2006 David N. Schramm Award for writing about high-energy astronomy, she is a member of the Board of Advisors for "400 Years of the Telescope".

Buhl *continued from page 3*

Neighborhood").

In 1995, Buhl Planetarium diversified its science programming by creating a show about the human body. *"Journey into the Living Cell"* was developed in collaboration with Carnegie Mellon University. It was followed by "*Gray Matters: The Brain Movie*", in 2000. In 2003, Buhl Planetarium introduced the program *"Tissue Engineering for Life"*, sponsored by the National Institutes of Health and GlaxoSmithKline Consumer Healthcare. This innovative program includes segments on stem cell research, the heart and the spine.

In September 2006 the Buhl Planetarium installed a full-dome digital projection system purchased with a $1 million gift from the Buhl Foundation. The visual impact and programming flexibility of this system has greatly expanded the nature and breadth of subject matter showcased in the planetarium. Although the new system is used extensively for astronomy programs, it also has application to other scientific fields, particularly the biological sciences, chemistry and engineering and architecture.

The Buhl Planetarium's latest production is *A Traveler's Guide To Mars,* based on the popular book by planetary scientist and artist William K. Hartmann. This full dome show takes the audience on a journey to the once-mysterious surface of the red planet Mars to glimpse research that will pave the way for a human expedition to this fascinating world. The show compares and contrasts the geological and watery pasts of Earth and Mars in a search for evidence proving that microbial life may once have existed on Mars.

CAPTIONS:

#1 — Buhl Planetarium and Institute of Popular Science (circa 1970)

#2 — Buhl Planetarium's "Theater of the Stars" under construction

#3 — Young visitors at the Buhl learn about America's Space Program

#4 — Buhl Planetarium shortly after it opened in 1939

About the US IYA2009 Logo

US IYA2009 has created a new logo specifically for national events and activities. (Please use the international logo for programs related to the major IYA cornerstone projects or other international ventures.) Please contact the US IYA program for permission for use. The US IYA project has also created a new giant postcard (2.8 MB PDF) that summarizes the major themes and programs that are being developed.

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