

400⁰ Years of Astronomical Telescopes

A Review of History, Science and Technology



September 29 - October 2, 2008

ESTEC 

Noordwijk

The Netherlands

Abstract Book

www.400yearsoftelescopes.org

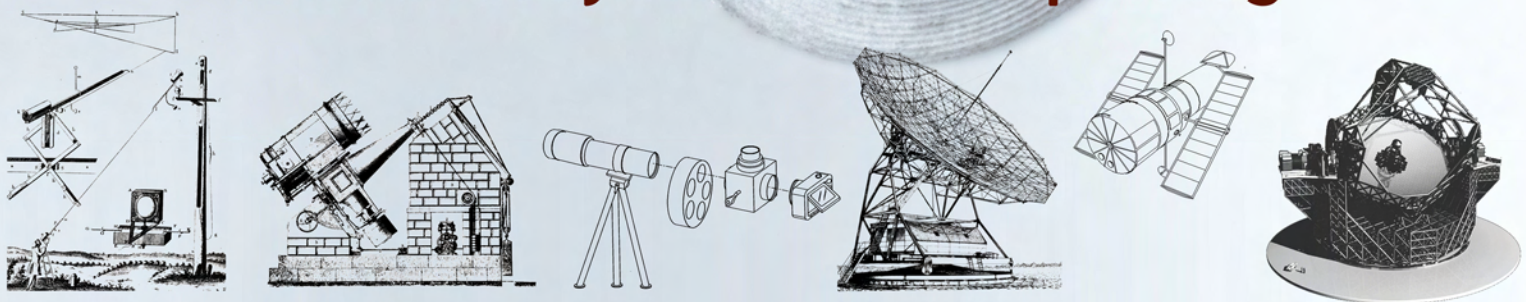


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Committees

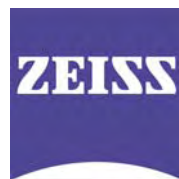
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Sponsors



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Programme

Monday, 29 September 2008

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- 12:00 The Era of Newton, Herschel and Lord Rosse
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- 14:10 In the Grip of the Big Telescope Age
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- 14:45 "Beautiful and Cantankerous Instruments": Telescopes, Technology, and the Changing Practice of Astronomy
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- 15:50 The History of Optical Instruments
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Tuesday, 30 September 2008

08:30 Registration

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18:30-21:00 Dinner Cruise

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The Beginnings in the Netherlands, from
Lipperhey to Huygens
Van Helden, A.
Utrecht University

It has always been clear that the telescope developed from spectacle lenses, but it was anything but clear how exactly that happened. Recent research has gone a long way toward solving this problem. When spectacles lenses became good enough, in the sixteenth century, the magnifying effect of this combination, given appropriate strengths, became obvious, but the image was blurred. By the beginning of the seventeenth century, the central area of the convex lens was sufficiently even in curvature for to produce a clear magnified image. Stopping the objective down was a counter-intuitive move, and Hans Lipperhey, a spectacle maker in Middelburg, may have been the first to do this. He certainly was the first to come forward with a working spyglass. His invention was examined by the States General in The Hague in the autumn of 1608 (they decided not to award a patent); less than a year later, Thomas Harriot in London and Galileo Galilei in Padua were examining the heavens with much more powerful versions of the instrument. Galileo was the central figure in the first chapter of telescopic astronomy, Christiaan Huygens was a central figure in the second chapter. The transition from the Galilean to the astronomical telescope in the 1640s made higher magnifications possible. However, optical problems, especially chromatic aberration—not theoretically formulated until the 1670s by Isaac Newton—meant that the curvature of the objective had to be minimized, and therefore higher magnifications could only be achieved by making telescopes longer. Huygens began with a comparatively modest telescope of about 3 meters and in 1655 discovered a satellite of Saturn. Four years later, he published the solution to the problem of Saturn's appearances that had vexed astronomers since Galileo. In this book, *Systema Saturnium*, Huygens also showed how angular diameters could be measured by inserting thin sticks in the focal plane of the telescope. Perhaps most interesting, he gave the dimensions of the solar system rather close to modern values. In telescope making, Huygens was the last of the scientists in the 17th century who made discoveries with a "home-made" telescope. Thereafter, professional telescope makers ruled the world of astronomical discovery. His final work, *Cosmotheoros*, published posthumously in 1698, was an exploration of the solar system with speculation about the inhabitants of other planets. As for Saturn's ring(s), Huygens still maintained, as he had in 1659, that it was a solid structure of appreciable thickness, while the consensus among the astronomers was that it was so thin that it

could be considered "a mere surface," and that it was a swarm of small objects.

Galileo's Telescope: History, Scientific Analysis,
and Replicated Observations

Strano, Giorgio
Istituto e Museo di Storia della Scienza

In the summer of 1609, Galileo Galilei started to improve upon the Dutch spyglass on the bases of scanty information received from his correspondents. Only a few months were needed to increase the magnifying power of the instrument up to the limit of thirty times. The process that Galileo followed to transform an optical toy into a perfected observational device is still subject to historical controversy. Such a transformation allowed Galileo to perform a completely new type of astronomical observation destined to change the traditional concept of the Universe. In light of the fourth centennial in 2009 of Galileo's astronomical use of the telescope, the Institute and Museum of History of Science of Florence is conducting a multi-approach research programme on the optical components of early Italian telescopes. Historical research is being merged with Scientific analyses conducted by the National Institute of Applied Optics in Arcetri, the National Institute of Nuclear Physics in Florence, and the Glass Experimental Station in Murano. The shape and composition of the lenses of early Italian telescopes are being studied by applying different state-of-the-art techniques: microphotography, interferometry, spectral transmittance and X-ray fluorescence. Moreover, the composition of early lenses and scientific glass objects are being compared. Finally, Galileo's reports of his observations are being analysed by mathematical methods and checked with an optical replica of Galileo's telescope held at the Astrophysical Observatory in Arcetri.

The Era of Newton, Herschel and Lord Rosse

Bennet, Jim
University of Oxford

That the story of the telescope from the late seventeenth to the mid-nineteenth century is not confined to the history of astronomy is more than a trivial observation that the instrument is used for a wider range of activities than the study of the heavens - in surveying, at sea, on the battlefield, in the theatre or opera house, and so on. Even when the heavens are involved and the practitioners are included in the history of astronomy, the relationship between the telescope and the discipline is not straightforward. Many of the prominent episodes in the instrument's development in the period take place in the British Isles and this talk will use several of them to illustrate the changing nature of that relationship with astronomy. To mention only the figure in the title, Newton's interest in the telescopes was much more optical than astronomical, while Lord Rosse's was arguable more mechanical. Of the three, Herschel's interest was most passionately directed to the skies, but ironically his contemporaries had most difficulty thinking of him as an astronomer.

The Great 19th Century Refractors

Lequeux, James
Observatoire de Paris

The first modern refractor was built in 1824 by Fraunhofer and Utschneider. Its diameter was 23 cm. Until 1883, all its successors had diameters smaller than 70 cm. Then came the era of giant refractors (aperture larger than 76 cm), culminating with the 102 cm telescope of Yerkes (1897) and the 125 cm horizontal refractor with siderostat for the 1900 Paris Universal Exhibition. This era was of short duration : the last giant (Allegheny, 76 cm) was completed in 1906. However several refractors with 60-67 cm diameter were still built until 1955. I will discuss why the cumbersome and expensive refractors were not dethroned for a long time by the silvered-glass reflecting telescopes, in spite of the advantages of the latter.

In the Grip of the Big Telescope Age

DeVorkin, David
Smithsonian Institution

George Ellery Hale was a man of many dreams. One of his most persistent was to find the means to collect as much light as possible. Writing in Harper's Magazine in 1928, he cried out: "Starlight is falling on every square mile of the earth's surface, and the best we can do at present is to gather up and concentrate the rays that strike an area 100-inches in diameter." Only a few months later, of course, the International Education Board of the Rockefeller Foundation answered his call to the tune of \$6 million dollars. Here we follow the growth of large reflecting telescopes during a period best called the "Hale era," commencing in the late 19th century, when the first large multi-focii photographic reflectors emerged during the reign of the great refractors, through to the onset of World War II when astronomical practice was dominated by 10 reflectors with mirrors between 60 and 100 inches, and was about to add one more whose surface area would almost double that of all the rest combined. We will touch upon issues of patronage, politics, institutional and national pride, as well as upon how design choice reflected both scientific priorities and technological limitations. The Hale era was not the first "Big Telescope Age" nor would it be the last. Here we will attempt to distinguish it from the others.

"Beautiful and Cantankerous Instruments": Telescopes, Technology, and the Changing Practice of Astronomy

McCray, Patrick
UCSB

Between the dedication of the 200" Hale Telescope in 1948 and the completion of today's 8-10 meter behemoths, astronomers' most iconic symbol, the telescope itself - its design, its technology, and its use - was transformed as a research tool.

The importance of this is deceptively simple: in astronomy, technological innovations have often led to new discoveries. Today, a new generation of eyes -flesh and blood, glass and steel - has turned to the sky with revitalized powers to observe the universe's diverse phenomena. Driven by the need to get as much observing time as possible and the desire to take advantage of the best observing conditions, modern observatories have experimented with new technologies and

modes of collecting images and spectra. This entailed a re-casting of the telescope by astronomers and science managers as a factory of scientific data and scientists as customers who order up astronomical data that is delivered to them electronically while they monitor the process through Internet links. At the same time, contemporary astronomers express considerable unease and apprehension about how these technological changes have altered, in ways subtle and profound, the nature of astronomical observing and what it meant to be an astronomer. This talk addresses the issues associated with these recent changes in astronomical practice and their connections to astronomers' desire for ever larger and more complex telescopes.

The History of Optical Instruments
Monnet, G.
ESO

The talk will cover the development of the Optical/IR instrumental toolbox (optics, smart focal planes, dispersers, detectors, adaptive optics correctors, photonic systems) and the evolution of astronomical instruments from small nimble opto-mechanical systems to today behemoths.

The History of Radio Telescopes
Sullivan, Woodruff
University of Washington

Forged by the development of radar during World War II, radio astronomy revolutionized astronomy during the decade after the war: a new universe centered not on stars and planets, but on the gas between the stars, on explosive sources of unprecedented luminosity, and on hundreds of mysterious discrete sources with no optical identifications. Using "radio telescopes" that looked nothing like traditional (optical) telescopes, radio astronomers were also a very different breed from traditional (optical) astronomers. This pathbreaking of radio astronomy also made it much easier for later "astronomies" and their "telescopes" (X-ray, ultraviolet, gamma-ray) to become integrated into astronomy after the

launch of the space age in the 1960s. This talk will trace the history of radio telescopes from 1945 through about 1990, from the era of converted small-sized, military radar antennas to that of large interferometric arrays connected by complex electronics and computers; from the era of strip-chart recordings measured by rulers to powerful computers and display graphics; from the era of individuals and small groups building their own equipment to that of large collaborations and national observatories.

History of Infrared Telescopes and Astronomy
Rieke, George
The University of Arizona

Infrared astronomy got off to many false starts for nearly a century before it really took root. The early efforts were hampered by a lack of knowledge about the large population of infrared-emitting objects besides stars, objects that now provide much of the focus for infrared astronomy. Even in stellar studies, the dominant issue was not detector technology, but the failure to develop a suitable photometric system that could provide the accuracy to study stars in the infrared quantitatively. When infrared astronomy finally took root, it was under the guidance of physicists not astronomers. Astronomy had also successfully grown into the radio and X-ray regimes, providing many non-stellar targets to investigate for infrared properties. The feedback between the resulting discoveries and an experimental physical orientation toward improvements in telescopes and instrumentation produced explosive growth. This process led to very large telescopes designed to minimize the infrared backgrounds on the ground. In addition, there has been a sequence of very high performance cryogenic telescopes in space. Through these developments and the parallel progress in infrared detectors and detector arrays, the capabilities for infrared astronomy have doubled roughly every seven months for the past 20 years and promise to continue to improve at this pace for some time.

History of X-ray Telescopes and Astronomy

Giacconi, Riccardo
Johns Hopkins University

Beginning and development of x-ray telescopes. Use of x-ray telescopes in Solar and Extrasolar Observations. The Improvement in sensitivity (10×10) and in angular resolution (300) from 1960 to 2000 (Chandra). The impact of x-ray observations on stellar physics and cosmology.

History of Gamma - Ray Telescopes and Astronomy

Pinkau, Klaus
Max Planck Institut für Plasmaphysik

Abstract History of Gamma-ray Telescopes and Astronomy Klaus Pinkau Gamma - ray astronomy is devoted to study nuclear and elementary particle astrophysics and astronomical objects under extreme conditions of gravitational and electromagnetic forces, and temperature. Because signals from gamma rays below 1 TeV cannot be recorded on ground, observations from space are required. The photoelectric effect is dominant < 100 keV, Compton scattering between 100 keV and 10 MeV, and electron - positron pair production at energies above 10 MeV. The sun and some gamma ray burst sources are the strongest gamma ray sources in the sky. For other sources, directionality is obtained by shielding / masks at low energies, by using the directional properties of the Compton effect, or of pair production at high energies. The power of angular resolution is low (fractions of a degree, depending on energy), but the gamma sky is not crowded and sometimes identification of sources is possible by time variation. The gamma ray astronomy time line lists Explorer XI in 1961, and the first discovery of gamma rays from the galactic plane with its successor OSO - 3 in 1968. The first solar flare gamma ray lines were seen with OSO - 7 in 1972. In the 1980's, the Solar Maximum Mission observed a multitude of solar gamma ray phenomena for 9 years. Quite unexpectedly, gamma ray bursts were detected by the Vela - satellites in 1967. It was 30 years later, that the extragalactic nature of the gamma ray burst phenomenon was finally established by the Beppo - Sax satellite. Better telescopes were becoming available, by using spark chambers to record pair production at photon energies > 30 MeV, and later by Compton telescopes for the 1 - 10 MeV - range. In 1972, SAS - 2 began to observe the Milky Way in high energy gamma rays, but, unfortunately, for a very brief observation time only due to a failure of tape

recorders. COS - B from 1975 until 1982 with its wire spark chamber, and energy measurement by a total absorption counter, produced the first sky map, recording galactic continuum emission, mainly from interactions of cosmic rays with interstellar matter, and point sources (pulsars and unidentified objects). An integrated attempt at observing the gamma ray sky was launched with the Compton Observatory in 1991 which stayed in orbit for 9 years. This large shuttle - launched satellite carried a wire spark chamber "Energetic Gamma Ray Experiment Telescope" EGRET for energies > 30 MeV which included a large Cesium Iodide crystal spectrometer, a "Compton Telescope" COMPTEL for the energy range 1 - 30 MeV, the gamma ray "Burst And Transient Source Experiment" BATSE, and the "Oriented Scintillation - Spectrometer Experiment" OSSE. The results from the "Compton Observatory" were further enlarged by the SIGMA mission, launched in 1989 with the aim to closely observe the galactic center in gamma rays, and INTEGRAL, launched in 2002. From these missions and their results, the major features of gamma ray astronomy are: - diffuse emission, i.e. interactions of cosmic rays with matter, and matter - antimatter annihilation; it is found, "...that a matter - antimatter symmetric universe is empirically excluded..." - nuclear lines, i.e. solar gamma rays, or lines from radioactive decay (nucleosynthesis), like the 1.809 MeV line of radioactive ^{26}Al ; - localized sources, i.e. pulsars, active galactic nuclei, gamma ray burst sources (compact relativistic sources), and unidentified sources.

History of Solar Telescopes

Von der Lühe, O.
Kiepenheuer-Institut für Sonnenphysik

Solar observations were done with telescopes since their invention - already Galileo looked at the Sun. Despite the Sun's unusual brightness, telescopes which specialize on solar observations are fairly recent, dating from the late 19th century onwards. Today, many solar telescopes have rather little in common with nighttime telescopes. They are adapted to high light flux, a limited range of declination, and to the specifications of solar spectrographs and polarimeters. This talk presents the history of the modern optical solar telescope on the ground and in space, the accompanying evolution of scientific capabilities, and a brief outlook into the future.

Imaging VHE Gamma-Ray Telescopes

Voelk, Heinrich J.¹; Bernloehr, K.²

¹Max-Planck-Institut fuer Kernphysik, Heidelberg;

²Max-Planck-Institut fuer Kernphysik, Heidelberg;
Institut fuer Physik, Humboldt-Universitaet zu
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The last 20 years have seen a rising number of detections of gamma-ray sources in the Very High Energy range (VHE; $0.1 \text{ TeV} < E < 100 \text{ TeV}$). These results were achieved with ground-based imaging telescopes that register the Cherenkov light emission by the electrons and positrons from the electromagnetic shower of secondary particles which a primary gamma quantum generates by interacting with the nuclei of atmospheric atoms and molecules. In this sense the Earth's atmosphere is part of the detector. The UV/optical Cherenkov radiation from the ultrarelativistic shower particles is imaged by large optical mirrors onto an array of fast photomultipliers that form the pixels of a "camera". The astronomical breakthrough of this observing technique came only in the last few years through the use of $> 10\text{m}$ sized mirrors in a stereoscopic arrangement of several telescopes. They have sufficient sensitivity and gamma-hadron rejection power to overcome the strong background produced by the charged particles of the Galactic Cosmic Rays that impinge on the atmosphere. The characteristics of these telescope systems are described. With an angular resolution of several arc minutes they compare favorably with satellite instruments and have led to the detection of about 100 Galactic and Extragalactic sources, in particular also in the plane of the Galaxy. A corresponding survey - which is still being extended at present - shows an amazing multitude of Galactic sources with an angular extent up to several degrees, from a variety of source populations. More often than not these sources are spatially resolved at VHE energies. Of special significance are Supernova Remnants whose non-thermal emission and morphology strongly suggests them as the long-sought sources of the Galactic Cosmic Rays. The VHE measurement of one such Supernova Remnant source is discussed in detail.

History of Neutrino Telescope/Astronomy

Suzuki, Atsuto¹; Koshiba, Masatoshi²

¹KEK, High Energy Accelerator Research
Organization; ²University of Tokyo

The first extraterrestrial neutrino observation embarked with the motivation to look into the interior of the sun. Thereby it was expected to test directly the stellar evolution and nuclear energy generation in stars. In 1968, the Homestake experiment led by R. Davis Jr. reported the first result which showed the deficit of neutrino events relative to solar model predictions. This conflict called the solar neutrino problem. In 1986, Kamiokande led by M. Koshiba was ready to detect the solar neutrino with the capability to measure the time, the direction and the energy spectrum concerning the incident neutrino. In 1989, Kamiokande confirmed the solar neutrino deficit, which had been long-standing since the Homestake result. In less than two months after the beginning of the Kamiokande solar neutrino data taking, a bunch of billions upon billions of extragalactic messengers swept through the Earth. They were the Supernova SN1987A neutrinos. The SN1987A occurred in the Large Magellanic Cloud, being 170,000 light years away from the solar system. Starting at 16:35:35 (JST) on February 23, 1987, 11 neutrino events were observed in Kamiokande within 13 seconds. Based on the energies of each event and the number of observed events, it was predicted that the origin of a supernova is the gravitational collapse of the iron core of massive stars and 99 % of the released gravitational energy is carried out by neutrinos. It confirmed the basic idea of the core collapse model. R. Davis Jr. and M. Koshiba shared the 2002 Nobel Prize in physics. Their citation reads *for pioneering contributions to astrophysics, in particular for the detection of cosmic neutrinos*. In 1998, Super-Kamiokande unveiled for the first time decisive evidence that neutrinos have mass. Atmospheric neutrinos are produced by high-energy collisions of cosmic rays with the Earth's upper atmosphere and come in two types called electron- and muon-neutrinos. Super-Kamiokande found that the number of electron-neutrinos detected was consistent with theorized totals, while the number of muon-neutrinos was significantly lower. The only explanation given the data, is that muon-neutrinos were oscillating, or changing from one type of neutrino to another, which could occur only if they have non-zero masses. The three years 2001 to 2003 were the golden years of solar neutrino research. In this period, a mystery of solar neutrino deficit was solved. Combining the SNO and the Super-Kamiokande measurements revealed that the electron-neutrinos produced in the interior of the Sun were changed into muon- and tau-neutrinos by the time they reach the Earth. Thus, the solution to the solar neutrino deficit was the solar neutrino oscillation.

KamLAND observed a deficit in the detected number of anti-neutrinos emitted by nuclear power reactors. KamLAND verified independently the solar neutrino oscillation under the CPT invariance, and significantly improved our knowledge of the parameters that characterize neutrinos. In 2005, KamLAND measured for the first time neutrinos produced by radioactive decays deep inside the Earth, so-called geoneutrinos. The heat generation of the Earth is the basic factor to understand the interior dynamics of plate tectonics, mantle convection and terrestrial magnetism. KamLAND opened up the new neutrino telescope. In the next decade, neutrino astronomy will move beyond our cosmic neighborhood and will detect distant sources such as active galactic nuclei, supernova remnants, and gamma ray bursts.

Astrometry from Tycho Brahe to Hipparcos

Hoeg, Erik

Niels Bohr Institute, Copenhagen University

Galileo Galilei's use of the newly invented telescope for astronomical observations resulted immediately in epochal discoveries about the physical nature of celestial bodies, but the advantage for astrometry came much later. The quadrant and sextant were pre-telescopic instruments developed by Tycho Brahe 1570-1590 for measurement of large angles between stars. Many decades after invention of the telescope these instruments fitted with telescopic sights were quite successful, especially in the hands of John Flamsteed after 1675. The meridian circle was a new type of astrometric instrument, invented and used by Ole Rømer already about 1705, but it took a hundred years before it could fully take over. The centuries long evolution of techniques is reviewed, including the use of photoelectric astrometry and space technology in the first astrometry satellite, Hipparcos, launched by ESA in 1989. Hipparcos made accurate measurement of large angles a million times more efficiently than could be done about 1960, and it will soon be followed by Gaia which is expected to be another one million times more efficient for astrometry.

History of Astronomical Discoveries

Longair, M.

Cavendish Laboratory, University of Cambridge

A number of case studies will be presented which illustrate the wide diversity of routes to astronomical, astrophysical and cosmological discovery. Prime ingredients include new technology, precision observation, extensive databases, capitalising upon discoveries in cognate disciplines, imagination and luck. The changing perspective on the essential tools for tackling frontier problems and astronomical advance will be discussed.

Capabilities of Amateur Telescopes

Koschny, Detlef

ESA/ESTEC

When the author starting getting interested in astronomy about 35 years ago, amateurs used mainly long-focus refracting or reflecting telescopes for visual observations. Telescopes on parallactic mounts normally could be fitted with a motor drive to follow the stars automatically. Telescopes were used for visual observations, and only advanced amateurs worked photographically, using chemical film. Nowadays, even small telescopes can be equipped with a mount which uses a GPS receiver, has simple 'one-star' alignment setup to know its orientation in space and allows on-click pointing to interesting celestial targets. Motor drives have sophisticated electronics compensating for periodic error in the worm gears up to compensating for flexure in the optical tube. The advent of reasonably priced CCD cameras have allowed a large number of amateurs to provide scientifically useful data. Active optic systems compensate for the turbulence of the air; computer-controlled filter wheels and mounts which can be pointed by clicking on a planetarium software make the technical capabilities of amateur telescopes supercede some of the professional scopes. This presentation gives an overview over the capabilities of modern amateur telescopes, draws some comparisons to what was available 35 years ago, and also presents some of the limitations of current amateur systems.

Building the Hubble Space Telescope
O'Dell, C.R.
Vanderbilt University

Building the Hubble Space Telescope (HST) presented many major technical challenges. Although the design of the observatory had been studied earlier, the final design solidified only when the project was constrained to deployment by the Shuttle Transportation System. This imposed obvious limits on its size and mass, but also presented the opportunity for building the first orbital facility that would achieve long life and flexibility through being periodically serviced by astronauts aboard the Shuttle.

The greatest challenges in building the observatory were associated with the pointing and control system and achieving a diffraction limited long-exposure image. In spite of its significant cost, the HST program was severely cost-constrained, which directly contributed to not detecting a flaw in the shape of the primary mirror.

Fortunately, today's HST performs at the high level originally sought because corrections for the mirror flaw were incorporated in a dedicated corrective-optics unit and small design changes in the optics of the evolving scientific instrument complement.

Zooming in on the Galactic Center
Genzel, Reinhard

Max Planck Institute for Extraterrestrial Physics

In the past decade high resolution measurements in the infrared employing adaptive optics imaging on 10m telescopes have allowed determining the three dimensional orbits stars within ten light hours of the compact radio source SgrA* at the Center of the Milky Way. These observations show that SgrA* is a three million solar mass black hole, beyond any reasonable doubt. The Galactic Center thus constitutes the best astrophysical evidence for the existence of black holes which have long been postulated, and is also an ideal 'lab' for studying the physics in the vicinity of such an object. Remarkably, young massive stars are present there and probably have formed in the innermost stellar cusp. Variable infrared and X-ray emission from SgrA* are a few probe of the physics and space time just outside the event horizon.

**Technology: Mirror Casting, Polishing,
Segmentation and Active Optics**

Noethe, Lothar
ESO

Throughout most of the history of the telescope the reflecting telescopes have been in competition with the refracting telescopes. The enormous advantage of the absence of chromatic aberrations has always been confronted with a few fundamental problems: the casting of the blanks which is related to the choice of the material, the optimization of the reflectivity, the polishing and the testing of the surfaces. The progress in these fields has in most cases been characterized by abrupt and revolutionary developments like the choice of bronze for the early metal mirrors or the invention of the silver coating and knife-edge test method, followed by rather tedious optimizations like the optimum choice of the substrate or the polishing and testing in the early days. Only in the last century, when the size of the telescope surpassed the one meter range, the reflecting telescope became the dominant type. The problems of polishing and maintaining the optical prescription were largely solved by introducing concepts like active optics and segmentation, both of them made possible to a great extent by using computers and control technology.

**Telescope Designs: Technology Keeping Up with
Design or Vice Versa**

Spyromilio, Jason
European Southern Observatory

The design of the telescope is closely linked to the technology of sensing. The speed of the optics defines in many ways the options for the telescope mount. The history of the telescope mechanics shall be reviewed with a view to the various drivers that pushed telescopes down particular cul-de-sacs.

A Breakthrough in Astronomy: the Advent of Adaptive Optics

Léna, Pierre

Université Paris Diderot et Observatoire de Paris

Atmospheric seeing was considered as an absolute limitation for angular resolution of ground-based optical telescopes, until the 1970s, exactly at the time of the conception of the new generation of giant telescopes, as the VLT. Emerging in the context of the cold war with many classification constraints, but with the new possibilities of digital control, astronomical adaptive optics was demonstrated in 1989 and progressively convinced of its potential an initially skeptical astronomical community. Twenty years later, it is a mandatory ingredient for the planning of Extremely Large Telescopes on Earth surface, and has allowed many discoveries, including on extragalactic objects. It even begins to contribute in other wavelengths range, like the millimetric one. Some directions for new developments will also be discussed.

Technology: Interferometry (all wavelengths)

Quirrenbach, A.

LSW Heidelberg

Abstract not available

The Rise of the Submillimetre

Robson, Ian

UK ATC

The submillimetre is probably the last part of the e-m spectrum to be developed from the ground and there are four key conditions for its recent huge success: suitable sites; purpose-built telescopes; improvement in detector technology; better understanding and hence minimisation of noise from the atmosphere. The review will highlight the development of all four key areas and use examples of the various facilities and astronomical discoveries to illustrate the dramatic rise of the submillimetre. I will also give a very brief look to the future in terms of submillimetre capability.

Back to the Future: Technology Directions for Radio Astronomy

Cordes, James

Cornell University

The early days of radio astronomy yielded a "Cambrian explosion" of telescope types, some of which survive to the present. In recent years, the drive for greater sensitivity --- combined with the need for high angular resolution along with wide fields of view in imaging, spectroscopic and time-domain applications --- has led to a new era of experimentation. I will summarize the scientific motivation and technology trends for construction and planning since about 1990. Relevant elements include innovative telescope optics and feed designs, large single reflectors vs. arrays, tradeoffs between analog and digital elements, and hardware vs. software processing. The discussion will include examples taken from the long list of telescopes now under construction or planned for the next decade.

Realisation of X-ray Telescopes - from Design to Performance

Aschenbach, Bernd

MPE Garching

For more than 40 years the building of X-ray telescopes for solar and astronomical observations has been practised with significant performance improvement. I will review the various techniques applied emphasising the impact of proper mirror material choice, grinding and polishing improvements and the role of metrology.

Technology: Gamma Ray Telescopes

Gehrels, Neil

NASA-GSFC

Gamma ray astronomy is currently in an exciting period of multiple missions and a wealth of data.

The advancement of the field since the 1950's closely follows the development of technologies for photon detection, spectroscopy and imaging. The early instruments used predominantly scintillation detectors. Imaging was crude with on-source / off-source measurements with collimated detectors. At high energy pair production instruments used spark chambers to track electrons and positrons. In the 1970's solid state germanium detectors were developed for high resolution spectroscopy. Coded aperture imaging began providing more precise source maps. Development of CdZnTe room-temperature solid state detectors in the 1990's has enabled large area, finely pixelated detector planes for sensitive imagers for low energy gamma-rays. Solid-state detectors are also key to new Compton and pair telescopes for medium and high energy telescopes. High precision imaging using focusing technologies and high resolution spectroscopy in large area formats are new upcoming technologies that promise a bright future. The talk will be a pictorial history of technology development of gamma-ray telescopes.

ESO's Past and Future
Woltjer, Lodewijk
Observatoire de Haute-Provence

ESO came legally into being 44 years ago after a decade of preparatory activities. Initial aims of the six country collaboration were modest; when in 1976 the 3.6-m telescope had been completed it was only the sixth of the world's telescopes in size, and it was far from innovative. Moreover, other countries in Europe developed comparable observatories nationally.

The European dynamics began to change when in 1982 Italy and Switzerland joined ESO, which by that time had initiated studies of much larger facilities. This provided funding for the New Technology Telescope and showed that ESO could develop and construct technologically advanced instruments in a cost effective manner. The increased confidence of the member countries allowed the VLT to be built, arguably the world's largest high performance telescope. Its successful completion caused several additional countries to join ESO, including the U.K. which 41 years earlier had concluded in Hoyle's words that it "never was going to work".

ESO had established an enviable record with the NTT constructed below and the VLT at budget.

Unfortunately, the somewhat irresponsible claims about the financial feasibility of the 100-m OWL telescope has somewhat tarnished this record. ESO's role in ALMA has brought it in contact with the mm radio community, a role justified by its experience in managing large projects in Chile.

This raises the issue of how expandable an organization like ESO is, something that has been discussed in the context of the Square Kilometer Array in radio astronomy. Would it really be wise to put all one's eggs in one basket?

Telescope Technology to Harvest Solar Energy
Angel, Roger
The University of Arizona

Large future telescopes such as the LSST will give an early alert of a potentially catastrophic asteroid impact. Telescopes in space also play a crucial role in monitoring climate change, whose consequences could be similarly disastrous. Here we consider how optical and radio telescope technology developed over the past 400 years may be applied to help reverse climate change. The sun delivers enough energy to the world's deserts to completely replace fossil fuel and satisfy the world's energy needs many times over. Solar energy can be converted to electricity during the day, stored as necessary and transmitted to population centers. Telescope technology comes into play in the conversion step, because the highest efficiency is obtained when the sunlight is focused. Both photovoltaic and thermal/mechanical converters can achieve efficiency as high as 40%, given concentration up to 1000 times solar level. But practical application is presently uneconomical, mostly due to the high cost of focusing optics and the 2-axis trackers needed to point them at the sun. The optics and tracking accuracy of astronomical telescopes are complete overkill for solar concentrators, by a factor of around 10,000 for optical telescopes and an order of magnitude for radio. Costs are too high by similar factors. But the principles and tools used in telescope design and manufacture are directly relevant to low-cost solar concentrators. Other common aspects are the need for very high throughput, operation in windy environments and the requirement for clear skies. Steward Observatory's Mirror Lab, which makes the largest astronomical mirrors, is now developing fabrication methods aimed at solar mirror production at the 500 tons/day rate of a float glass factory. For 4 mm-thick, back-silvered,

paraboloidal mirrors, this rate corresponds to 18 km²/year, which would yield the electrical power of a conventional 1 GW station. Solar energy from float glass from 50 factories could increase the energy supply at the same rate as the new coal fired plants being built in China. Making two-axis trackers at a commensurate rate will be challenging. For example, a 100 m² tracker would have to be manufactured and put into operation every 3 minutes, 24/7, to keep up with just one float glass plant. To keep down tracker cost, optical designs are being developed that provide for efficient operation of an array of multijunction photovoltaic cells at each reflector focus, with the maximum tolerance to tracking error despite the high concentration. The optics are also designed so the trackers can be built with high structural efficiency and the minimum amount of steel per unit area of collection. The designs are consistent with mass produced trackers costing ~\$100/m², corresponding to ~\$0.5/watt (peak).

Telescopes and Sacred Mountains

Hasinger, Günther¹; Kudritzki, R.-P.²

¹*Max-Planck-Institut für Extraterrestrische Physik;*

²*IfA Hawaii*

The authors discuss their experience with the delicate balance between scientific requirements for the best astronomical sites on one hand and the environmental and ethnic concerns on the other hand. In particular, examples on Mt. Graham (Arizona) and Mauna Kea (Hawaii) will be discussed.

Environmental Threats to Astronomy - What to Do?

*Crawford, David
Consultant*

Have you noticed the growing adverse environmental impacts on observing conditions? If you haven't, you will or you are blind. These include climate and atmospheric change (label it caused by global warming if you like), space debris, radio frequency interference, and light pollution. Most of these affect the public as well

as astronomy. All of these adverse impacts have been around for some time but are growing at an increased pace worldwide and can and will be serious threats to current and planned observing sites. Getting positive change is a huge job, needing political, social, and technical networking and action. We must be proactive, beginning now. The threat cannot be ignored. This paper summarizes the problems and potential solutions.

The Role of Observatories in Underdeveloped Countries

Govender, Kevindran

South African Astronomical Observatory

Astronomy is often regarded as an esoteric science with little visible impact on development. How does one justify the large investments in telescopes and astronomical research while there are people living in poverty? Within the South African context the government has taken bold steps that are often regarded as controversial. They have invested in the Southern African Large Telescope (SALT), the largest single aperture optical telescope in the Southern Hemisphere, and continue to invest heavily in the bid (and demonstrator telescope called MeerKAT) for the Square Kilometre Array, the largest radio telescope array ever built. Being a country where about half the population live below the poverty line, South Africa has embarked on a visionary journey in recognition of the importance of astronomy for development. The SALT Collateral Benefits Programme (SCBP) was established in conjunction with the decision to build SALT. The purpose of the programme is to ensure that tangible benefits are reaped from this investment and from astronomy in general. This presentation will cover the basics of SALT design (regarded as a cost effective 10m class telescope) and explore its developmental role within South Africa and the whole continent of Africa by looking at the activities of the SCBP. The importance of observatories and astronomy for development has contributed to the declaration by the United Nations of 2009 as the International Year of Astronomy (IYA2009). This presentation will also explore one of the Global Cornerstone projects of IYA2009 entitled "Developing Astronomy Globally" which is aimed at exploiting the benefits of astronomy for developing regions.

**Telescopes Seen Through the Lens of
Scientometrics**
Trimble, Virginia
UC Irvine and LCOGT

Deciding the importance of scientists and their tools can, in the long run, be left to the verdict of history if you are in no hurry and don't mind if the answer shifts every decade or two. For the present moment, there are referees' reports on your papers and proposals (not unbiased perhaps). Just a little further back, we can carry papers and proposals (not unbiased perhaps). Just a little further back, we can carry out quantitative studies of publications - numbers of them and the rates at which they are cited both shortly and longly after publication. The talk will attempt to bridge the temporal gap between historical and scientometric methods, by pushing the latter back as far as possible for both run of the mill and superstar facilities and papers. A predictable result is that, although many major astronomical discoveries were made with telescopes that we would now regard as derisorally small, these facilities were frequently (not always) the largest and/or most precise and expensive of their epoch.

Space Astronomy as Very Big Science
Smith, Robert; Smith, W.
University of Alberta

Large-scale space astronomy projects have been a central element in the physical sciences since the 1960s, especially in North America, Europe and Japan. Built with the support of national governments, often working together in international partnerships, these projects have cost hundreds of millions or even billions of dollars and have engaged the efforts of armies of scientists and engineers. As such, they have been among the biggest sorts of Very Big Science.

The largest of these projects have typically taken decades to bring to fruition, and the journey from conception to completion for such endeavours has usually been fraught with assorted difficulties. The management efforts called forth by such enterprises have also presented daunting challenges which have often proven as formidable as the technical and economic challenges. In this paper, I will examine these management challenges and how they have helped shaped the

directions taken by space astronomy. In so doing I will draw on a range of examples, but will concentrate particularly on the history of the Hubble Space Telescope.

**Conceiving and Marketing NASA's Great
Observatories**
Harwit, Martin
Cornell University

In late 1984, Dr. Charles P. (Charlie) Pellerin Jr., director of the Astrophysics Division of NASA's Office of Space Science and Applications (OSSA) faced a dilemma. Congress and the White House had given approval to work that would lead to the launch of the Gamma Ray Observatory (GRO) and the Hubble Space Telescope (HST), but competing segments of the astronomical community were clamoring for two additional missions, the Space Infrared Telescope Facility (SIRTF) and the Advanced X-ray Astrophysics Facility (AXAF). Pellerin knew that Congress would not countenance a request for another costly astronomical space observatory so soon after approving GRO and HST. And a request for simultaneous approval of both AXAF and SIRTF had no chance at all. He also foresaw that if he arbitrarily assigned priority to either AXAF or SIRTF he would split the astronomical community. The losing faction would be up on Capitol Hill, lobbying Congress to reverse the decision, and Congress would do what it always does with split communities --- nothing.

Pellerin decided to call a meeting of leading astrophysicists to see how a persuasive argument could be made for both these new observatories, and to market them as vital to a first comprehensive inventory of the universe conducted across all wavelength ranges. He set up what came to be known as the Astrophysics Council, but was officially designated as the Astrophysics Management Operations Working Group (AMOWG). From its initial meeting on January 3, 1985, until stepping down in late July, 1987, I chaired this Council. We helped Pellerin come up with a scientific rationale for the cluster of four Great Observatories --- GRO, HST, AXAF (now known as Chandra) and SIRTF (now Spitzer). The Council provided Pellerin a rotating membership of leading astrophysicists, who could debate and resolve issues so that decisions he reached would have solid community support. It also helped him to market his ideas in Congress, where he as a government official was precluded

from lobbying, whereas Council members, acting as individual scientists, were free to walk the halls of Congress and make their opinions known to members of Congress and Congressional staff. Ultimately, the concept of the Great Observatories came to be accepted by Congress; but its implementation faced myriad difficulties. False starts, political alliances that never worked out, and dramatic changes of direction necessitated by the Challenger disaster of early 1986 continually kept progress off balance. My paper follows these twists and turns as documented in the minutes of the Astrophysics Council and the many letters exchanged with Council members, NASA officials, the Space Science Board, the President's Science Advisor, and many others in the two and a half years I was active. My paper ends with the news on February 1, 1988, that President Ronald Reagan had sent his 1989 budget proposal to Congress with funding intended to provide AXAF a new start. The implementation of SIRTf would follow years later.

Future Technologies for Telescopes and Instruments

Cunningham, Colin
UK Astronomy Technology Centre

The theme of this conference is the evolution of telescopes over the last 400 years. I will give my view of what the major leaps in technology have been, and attempt to predict what new technologies could come along in the next 50 years to change the way we do astronomy and help us make new discoveries. Are we approaching a peak of innovation and discovery, and will this be followed by a slow decline (as predicted by Martin Harwit in 1981)? Or are there prospects for even further technology leaps and consequent new discoveries? Will global resource and financial crises bring an end to our great ambitions, or will we continue with bigger telescopes and more ambitious space observatories?

Challenges and Perspectives for Future Telescopes

de Zeeuw, T.
ESO

Technological developments now make it possible to observe planets orbiting other stars, peer deeper than ever into the Universe, use particles and gravitational waves to study celestial sources, and to carry out in situ exploration of Solar System objects. This promises tremendous progress towards answering key astronomical questions such as the nature of dark matter and dark energy; physics under extreme conditions including black holes, supernovae and gamma-ray bursts; the formation and evolution of galaxies from first light to the present, and the formation of stars and planets including the origin of our own Solar system and the beginning of life. These are amongst the most fundamental questions in all of science and are of enormous interest to the general public.

A wide range of general purpose and dedicated observatories, on the ground and in space, is presently in operation or under development. Plans are being drawn up for a next generation of facilities, including extremely large telescopes for the optical and infrared, a radio telescope with very large collecting area, survey telescopes which would provide deep imaging of the sky every few nights, an advanced technology Solar telescope, wide-field imagers in space, advanced planetary and Solar missions, experiments to detect particles and gravitational waves, large X-ray telescopes, and space missions devoted to characterizing extra-solar planets. Construction of these facilities will require substantial investment by national funding agencies over the next decades. This requires the development of an integrated science vision which identifies the most promising techniques and facilities needed to make substantial progress, followed by a road map for the development of the required infrastructure. The talk will summarize recent activities in this direction, with emphasis on future ground-based facilities.

The Rise and Fall of Australian Colonial Observatories

Tasker, Ian
University of Western Sydney

Australian colonial observatories, through necessity, provided services for the maritime,

agricultural and local communities. These services included time-keeping, recording the tides, meteorology, magnetic & trigonometric surveys for land use etc. Their multi-disciplined contributions to the colonies, as appendages to their own observation and research programmes, eventually contributed to their own demise with the subsequent loss of public support. There are other contributing factors which must be accounted for, if we are to draw a complete and accurate historical picture on the rise and fall of Australian colonial observatories.

The theoretical framing of Australian science was practically ignored till Basalla (1967) put forward a diffusionist model which led to MacLeod's (1982) imperialist model and later to Inkster's (1985) systems perspective. Though all have drawn examples from Australian colonial science, supporting their notions of the scientific enterprise, none have ventured a discipline specific treatment. This project will investigate the rise and fall of Australian colonial observatories within the theoretical frameworks mentioned above.

Alhazen: The Book of Optics

Hoeg, Erik

Niels Bohr Institute, Copenhagen University

Alhazen or Ibn al-Haytham has sometimes been called the "father of optics" and "the first scientist". His Book of Optics in seven volumes appeared in Cairo 1021 and had great impact on the development of European science in the following centuries. The scientists discussing optics are called "perspectivists" after Roger Bacon's book "Perspectiva" from about 1270, but the word perspective has here a very different meaning from that in the Renaissance art of painting. Perspective meant the science itself about seeing and the perspectivists thought that optics gave a deep insight into how we get to know anything about the world. It begins with the emission of light and colours from the objects through air to the eyes and then to the brain. This view is based on Alhazen's book which was considered the most important book on optics until Johannes Kepler's "Astronomiae Pars Optica" from 1604. The Book of Optics in a printed version from 1572 is found in the Leiden University Library in the Latin translation from the Kitab al-Manazir (Book of Optics). The ideas of light by Alhazen and the perspectivists will be explained and copy of

some pages from the book in Leiden will be displayed.

History of Development of Astronomical X-ray Telescopes in the Eastern Europe

Hudec, Rene

Astronomical Institute

The design and development of the space X-ray telescopes started in former Czechoslovakia in 1969 with the first X-ray telescope flown in 1979. These efforts were part of the former INTERCOSMOS space program, an East European and Soviet equivalent to ESA. 8 space X-ray telescopes were flown of 4 spacecrafts and space probes, including the large X-ray telescope on Soviet Salyut 7 orbital station in 1981. Almost all INTERKOSMOS and soviet spacecrafts with X-ray telescopes onboard used optics of Czech production. We describe shortly the motivation, the history, as well as the performed experiments as well as the technologies designed and developed. After the velvet revolution in 1989, the development of astronomical X-ray optics continued in new conditions, with emphasis on design, developments and tests of various innovative technologies.

Astronomical X-ray Telescopes of Lobster Eye Type

Hudec, Rene¹; Pina, L.²; Sveda, L.²;

Inneman, A.³; Semencova, V.³; Skulinova, M.¹

¹Astronomical Institute AS CR; ²CTU; ³RITE

The astronomical X-ray telescopes of Lobster-Eye (LE) type represent a promising alternative to classical X-ray telescopes which use mostly the Wolter 1 geometry. The main preference of LE is the very large field of view of order of 100 square degrees and more, in contrast to less than 1 degree in the case of conventional X-ray telescopes. The results of developments in 1990-2008 resulting in construction and tests of several test modules are briefly described and discussed, together with scientific justification.

Precursors of the Hubble Space Telescope
Morton, Donald
National Research Council of Canada

A major step in the history of the telescope occurred with deployment outside the earth's obscuring and distorting atmosphere, benefiting research in every region of the electromagnetic spectrum. This report concentrates on the two original functions of the HST, UV spectroscopy and sharper images. In 1946 Lyman Spitzer described some of the scientific possibilities of observations from space, and that same year Richard Tousey installed a spectrograph with a 1 mm fish-eye lens on a V2 rocket to observe the sun. By the 1960's sounding rockets were making new discoveries about hot stars and the interstellar medium with simple instruments. Satellite missions followed with larger mirrors and longer integration times - the OAO series, the European TD-1A and ANS missions, and the collaborative IUE. The Stratoscope I and II balloons provided stable platforms for images with high angular resolution and BUSS recorded UV spectra around 2800 Å.

The Astronomical Telescope between Kepler and Newton
Mahoney, Terence
Instituto de Astrofísica de Canarias

Until telescopic sights were accepted by the astronomical community, there could be no further development of positional astronomy beyond the work of Tycho Brahe, who had brought astrometry to the limits of the acuity of the human eye. I describe the conversion of the Keplerian telescope into an instrument capable of making accurate measurements with the introduction of the micrometer in the focal plane and the Vernier scale on mounting circles in the 1630s. These improvements were vital to the observations of Flamsteed on which Newton relied for the verification of his theory of gravitation.

Galileo 1610: an Original Play for the International Year of Astronomy
*Larrouy, C. ¹; Lacoste, G. ¹; Blanc, M. ¹;
Blanc, E. ¹; Habibi, E. ¹; Baratte, Y. ¹; Gibert, B. ¹;
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In 2009, the International Year of Astronomy, we are going to celebrate the 4th centennial of the first astronomical discoveries of Galileo Galilei. These discoveries built upon a new means to observe the cosmos: the telescope, designed the year before by dutch scientists. On this occasion, we plan to design and produce an original play, "Galileo, the starry messenger". This show will optimally combine the technique of a theatre play with dance, music, black light and video, to set on stage the unique character of Galileo the man, performing his observations, questioning what he sees and dreaming about the extraordinary implications of his observations. This is indeed the man who was curious and daring enough to look at the sky in a different way, using for the first time an instrument that changed what he watched, not just to better see already known objects, but really to see different objects and reveal a fully different sky. This is what our show aims at carrying to the public: a close understanding of the man that first looked at the sky in a completely different way, opening the era of modern astronomy. Beyond Galileo, set on stage, we want to carry his new way of looking at the sky, and show how his vision, the very subject of our play, changed his and our relationship to the sky and the way we understand our own place in the cosmos. This drama, written by a Toulouse author, indeed builds on a scientific background, but our first goal is to share the excitement of this major scientific adventure with the public, adults and children alike. Our wish to communicate to the public the way a major scientific discovery was achieved, and a common understanding of its unique implications, drive our production of "Galileo, the starry messenger", with one major and important objective: make science the shared adventure of all humans.

Solar Telescopes of the Crimean Astrophysical Observatory: history of establishment and discoveries

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Abstract not available

Ukrainian T-Shape Radio Telescope UTR-2 and Ukrainian VLBI System URAN: 50 Years at the Service of Decameter Astronomy

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Abstract not available

The Infrared Space Observatory (ISO)

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ISO was the world's first true orbiting infrared observatory, following on from the pioneering IRAS survey mission. Equipped with four highly-sophisticated and versatile scientific instruments, it was launched by Ariane 4 in November 1995 and provided astronomers world-wide with a facility of unprecedented sensitivity and capabilities for a detailed exploration of the Universe at infrared wavelengths during its 29 months mission. The two spectrometers (SWS and LWS), a camera (ISOCAM) and an imaging photo-polarimeter (ISOPHOT) jointly covered wavelengths from 2.5 to around 240 microns for the first time, with diffraction limited resolution and mJy sensitivities. Its 60 cm diameter telescope was cooled by superfluid liquid helium to temperatures of 3 K and the FIR detectors to 1.8K. The mission was a great technical, operational and scientific success with most satellite sub-systems operating far better than specifications, including innovative cryomechanisms and stressed Ge:Ga arrays for the

200 micron range and monolithic mid infrared arrays. Its scientific results impacted practically all fields of astronomy. During its routine operational phase, which lasted until April 1998 - almost a year longer than specified, ISO successfully made some 30,000 individual imaging, photometric, spectroscopic and polarimetric observations ranging from objects in our own solar system right out to the most distant extragalactic sources. ISO was one of the most efficient telescopes even gathering science data during re-pointings and having two instruments gathering science data in parallel. ISO was also a trendsetter in developing a user-friendly, illustrative archive of its own mission, also compatible with the modern Virtual Observatory capabilities. ISO discovered water and organic molecules in many different places in the Universe, and allowed for a detailed inventory of cosmic dust and ices in comets, around newly born stars and in the interstellar space. ISO discovered that luminous infrared galaxies, powered by vigorous bursts of star formation, were much more frequent in the past than they are now. Stars in the very early stages were discovered in dust hidden regions. ISO was an ESA project with instruments funded by ESA Member States (especially the PI countries: France, Germany, the Netherlands and the United Kingdom) and with the participation of ISAS and NASA.

Observations with Small Telescopes at the Terskol Observatory: Results and Benefits

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ICAMER Observatory

The high-altitude observatory Terskol in the Northern Caucasus (3100m asl) has various astronomical facilities, which include optical telescopes (Zeiss-2000, Zeiss-600, the large solar telescope ACU-26, and some small telescopes), their instrumentation (high-resolution spectrometers, high-speed photometers, CCDs, etc.), as well as provisions for data distribution via modem and computer networks, and software packages. Since 1996, these instruments have contributed significantly to progress in discovery and monitoring of NEOs, precise astrometry and photometry of solar system bodies, high-resolution spectroscopy of interstellar clouds, search for optical afterglow of gamma ray bursts, etc.

Observational facilities of the Terskol Observatory are heavily used for the operation of the

Synchronous Network of distant Telescopes (SNT), which includes optical telescopes at Terskol and observatories in Bulgaria, Greece, and Ukraine; the remarkable results were obtained from synchronous observations of galaxies and flare stars.

The decade of successful research with SNT has yielded various analytical and numerical techniques to provide observations with distant telescopes. In 2006 the UNIT project (Ukrainian Network of Internet Telescopes) was initiated. It aims to use new technologies to promote modern astronomy and to create an interface between society and science. The philosophy of UNIT is to develop an instrument to perform observations over the Internet from a PC at any location and to provide real-time access to data. UNIT is being designed for both professional and educational applications.

Current status and prospects of international research projects, as well as observational facilities of the Terskol Observatory will be presented in this paper.

Fraunhofer Refractor at Tartu Observatory *AnnuK, Kalju* *Tartu Observatory*

We shall give a short overview about Fraunhofer Refractor at Tartu Observatory. We also describe some significant astronomical observations made with this telescope. 9.5" Fraunhofer Refractor (also known as Great Dorpat Refractor) was installed at Tartu Observatory in the end of 1824 by F.G.W. Struve. It was the best and most modern refracting telescope built at that time and Fraunhofer Refractor was for many years the largest achromatic refractor in the world. Tartu Observatory was also one of the best equipped observatory in the Europe during the period of about 1825-1840. The most important works made by F.G.W. Struve with Fraunhofer Refractor were detecting about 3100 double stars and measuring stellar parallax of Vega. Nowadays, the Fraunhofer Refractor has been reconstructed and it is as a museum piece at Old Tartu Observatory.

From Observation to Gaia Catalogue *Blasco, Carmen* *ESA*

Gaia will detect all celestial bodies down to the very faint magnitude 20, amounting to about a billion objects. The final Gaia Catalogue, containing the precise astrometric, photometric and spectroscopic details, is scheduled for publication in 2020. From the celestial object to the Catalogue, light has to enter Gaia instruments until the CCDs of the focal plane assembly, information has to be transmitted to a Gaia's ground station and finally processed by the Data Processing and Analysis Consortium.

The Gaia Spacecraft and Instruments *Blasco, Carmen* *ESA*

Within a launch mass of about two tonnes, the Gaia spacecraft comprises a payload module and a service module. The service module comprises all mechanical, structural and thermal elements supporting the instrument and the spacecraft electronics. Inside the satellite, Gaia's instruments are mounted on a hexagonal optical bench. The payload features two telescopes sharing a common focal plane, each looking out through an aperture in the payload housing. Gaia's photometric instrument consists of two low-resolution prisms dispersing all the light entering the field of view. In addition to the photometric instrument, Gaia features the Radial Velocity Spectrometer (RVS) instrument. The RVS provides the third component of the space velocity of each star down to about 17th magnitude. Gaia's astrometric measurements are made using the global astrometry concept successfully demonstrated by Hipparcos. Gaia measures the relative separations of the thousands of stars simultaneously present in the combined fields of view.

Gaia Mission Overview

Blasco, Carmen

ESA

High-accuracy astrometry will allow Gaia to exactly pinpoint the position of a star and to measure its movement across the sky, whilst spectroscopic measurements will allow the radial velocity to be determined. Gaia will also gather photometric data, measuring the brightness of a star in a few dozen colours. This array of data will reveal a moving, three-dimensional Milky Way map of unprecedented scope and precision, as well as providing profiles of the physical properties of each star, including luminosity, surface gravity, temperature and elemental composition.

Amateur Robotic Telescope

Nieuwenhout, Frans

AWSV Metius

ABSTRACT: A robotic telescope has been realised by members of AWSV Metius, an amateur astronomy club in Alkmaar, The Netherlands. Since start of operation in 2005, more than 10,000 pictures have been made by members of Metius who operate the telescope via internet. Some people make pretty pictures of globular clusters, galaxies and supernova remnants. Others conduct variable star observations which are submitted to the AAVSO. We also observed the first GRB afterglow from the Netherlands. A short description of the construction and some results will be presented.

Small Robotic Telescopes for HEA in Ondrejov

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We report on two small aperture robotic telescopes called BART and D50 operated in Ondrejov. Both telescopes are capable of automatic observation of gamma ray burst optical counterparts. Coordinates of GRBs are taken from

GCN alerts distributed via internet. Telescopes observe other interesting high energy sources when there is no GCN alert. The smaller telescope BART has aperture $D=254\text{mm}$. The bigger telescope D50 has aperture $D=500\text{mm}$. Both telescopes are controlled by GNU software RTS2 and are accesible through internet. We describe the two telescopes and related SW and show some results such as our first observed optical counterpart of GRB.

Gaia's Scientific Rewards

Blasco, Carmen

ESA

Gaia's key goal is a detailed study of the Milky Way that will reveal our galaxy's content, dynamics, current state and formation history. Besides this, however, the unprecedented accuracy and unbiased nature of Gaia's full-sky survey will also prove valuable, even revolutionary, to a huge range of scientific disciplines. In addition to galaxy studies, Gaia's wealth of data will eventually inform and invigorate areas as diverse as stellar life cycles, dark matter and general relativity. Furthermore, as a complete sky survey without pre-programmed targets, the discovery potential of Gaia is profound.

The Great Melbourne Telescope: A Contextual History

Gillespie, Richard

Museum Victoria

Great hopes were held for the Great Melbourne Telescope (GMT) when it was erected in Melbourne, Australia in 1869. Its design and construction was overseen by leading British astronomers. They agreed that its maker, Thomas Grubb in Dublin, had excelled in creating a telescope that would make great discoveries through studies of the southern hemisphere nebulae. The primary aim as to detect if any changes had occurred in the southern nebulae since Herschel's observations in the 1820s; were they sufficiently changed to confirm the 'nebular hypothesis' or were they resolvable into stars? Yet the telescope never lived up to early expectations.

Historians have tended to blame one or more aspects of the telescope design: the speculum mirror, its focal length, or wind vibration. Yet none of these issues, taken separately or collectively, are sufficient to account for the telescope's modest performance. Instead the telescope needs to be placed into its technical, institutional, astronomical and cultural contexts, for it was the interplay between these many aspects that shaped the telescope's working life. Like any new instrument, there were several technical problems with the telescope. The Melbourne astronomers could not remove a protective coating from one of the two 48 inch primary speculum mirrors, while the other primary did not give clear resolution for its first two years on the telescope. But these operating issues were gradually surmounted. The quality of the observers was a more intractable problem. The first observer selected and trained in England, proved to be unsatisfactory, as did the second. The GMT was also operating within a busy government observatory, responsible with its primary functions of timekeeping, building star catalogues, overseeing a geodetic survey, participating on other international astronomical projects, and maintaining meteorological and magnetic observations. Maintaining a troublesome large telescope could only be one priority among the many that confronted Government Astronomer Robert Ellery. This stands in contrast to the focussed research projects by the Herschels and Lord Rosse, whose success observing nebulae with large speculum telescopes had been the genesis for the Melbourne telescope. By the time the GMT was working well with a skilled observer, new developments in astronomy had started to weaken the significance of the telescope. The development of sensitive photographic plates in the 1880s allowed them to be used with smaller silvered-glass reflectors to produce photographs of nebulae that eliminated the idiosyncratic eye-to-hand observations of the individual observer. Although a spectroscope and camera were mounted on the GMT, it was not well suited to their use. By the 1880s too, the two primary mirrors were becoming tarnished, and laborious attempts to polish them and restore their figure failed. Melbourne Observatory joined the Carte de Ciel project and acquired a Grubb astrograph telescope. The GMT has left a legacy however. The GMT project established the reputations of Thomas Grubb and his son Howard as pre-eminent telescope makers. The GMT was eventually sent to Mount Stromlo Observatory in the 1940s, and transformed into Stromlo's 50 inch. With the destruction of the 50 inch by bushfires in 2003, there are plans to restore the GMT and reinstate it in its original building in Melbourne.

XMM-Newton: Across the X-ray Universe
Gonzalez-Riestra, Rosario; Rodriguez-Pascual, P.M.
XMM-Newton Science Operation Centre

This Poster is presented on behalf of the XMM-Newton Project

XMM-Newton is the second Cornerstone of ESA's "Horizons 2000" Programme and is the biggest science satellite ever built in Europe. Its telescope mirrors are the most sensitive ever developed in the world, with 200 square metres of highly polished gold.

The instruments on-board XMM-Newton (the EPIC cameras, the RGS spectrograph and the Optical Monitor) have been conceived and built by European scientific institutes. Each is managed by a Principal Investigator, heading teams of scientists and engineers from different countries.

XMM-Newton unique characteristics are:

- large field of view
- large collecting area
- high time resolution
- high spectral resolution
- ability to perform long interrupted observations
- simultaneous X-ray - UV - optical coverage

XMM-Newton is an Observatory type mission, with most of the time open to the whole astronomical community. Data are publicly available after a proprietary period of one year. More than 1800 publications using XMM-Newton data have appeared in refereed journals since launch (December 10th 1999). In November 2007 ESA SPC approved the extension of operations until the end of 2012.

AKARI: Space Infrared Cooled Telescope
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¹University of Tokyo; ²European Space Astronomy
 Centre, ESA

AKARI, formerly known as ASTRO-F, is the second Japanese space mission to perform infrared astronomical observations. It is a JAXA project with the participation of ESA as well as in collaboration with several universities and

institutes in Japan, the U.K., the Netherlands, and Korea. AKARI was launched on 2006 February 21 (UT) and successfully brought into a sun-synchronous polar orbit at an altitude of approximately 700km and inclination of 98.2 deg by a JAXA M-V rocket. AKARI has a cooled telescope with a primary-mirror aperture size of 685mm together with two focal-plane instruments on board: the Infrared Camera (IRC), which covers the spectral range 2-26 micron and the Far-Infrared Surveyor (FIS), which operates in the 50-180 micron wavelength range. The telescope mirrors are made of sandwich-type silicon carbide, especially developed for AKARI. The focal-plane instruments and the telescope are cooled down by a unique cryogenic system that kept the telescope at 6K for 550 days with 179 liter super-fluid liquid Helium (LHe), with the help of the mechanical coolers on board. Despite of the small telescope size, the cold environment and the detectors of the latest technology enable very sensitive observations in infrared wavelengths. To take advantage of the characteristics of the sun-synchronous polar orbit, AKARI performed an all-sky survey during the LHe holding period in four far-infrared bands with FIS and two mid-infrared bands with IRC, which surpasses the IRAS survey made in 1983 in sensitivity, spatial resolution, and spectral coverage. AKARI also made over 5000 staring observations at given targets in the sky for approximately 10 minutes each, for deep imaging and spectroscopy from 2 to 180 micron. The LHe ran out on 2007 August 26, after which the telescope and instrument are kept around 40K by the mechanical cooler on board and near-infrared imaging and spectroscopic observations with IRC are now being performed in staring mode.

Airborne Infrared Telescopes
Erickson, Edwin
NASA Ames Research Center

Convair 990: In 1967 Gerard P. Kuiper and Frederic F. Forbes installed a stabilized heliostat mirror with a 30-cm telescope and a Fourier transform spectrometer on the NASA Ames Convair 990 aircraft. With it they measured the 1.0 - 2.5 μm spectrum of Venus, finding - surprisingly - that its clouds were devoid of water. This pioneering work showed that airborne astronomy enables hands-on operation of current, innovative technology to make observations precluded from the ground by telluric water vapor.

Learjet Observatory: In 1968 Frank J. Low initiated far-infrared observations from aircraft

using bolometer detectors he had developed, and the NASA Ames Learjet. His clever 30-cm open-port telescope included the first chopping secondary mirror. This employed synchronous demodulation to suppress detected low frequency power fluctuations ("sky noise") emitted by the atmosphere, and minimized detection of extraneous radiation from the telescope. In the early 1970's, an improved Learjet telescope was developed at Ames to accommodate additional instrument teams. The telescope was gimbal-mounted, with an intentionally leaking air seal to permit gyro-stabilization. Guiding was done by the astronomer who viewed the sky through a 7.6-cm optical telescope. Some important Learjet findings were luminosities of star-forming molecular clouds, evidence for concentrated sulfuric acid droplets as the major constituent of Venus' clouds, and first detection of the important interstellar medium (ISM)-cooling C+ line at 158 μm .

Kuiper Airborne Observatory - KAO: A 91-cm telescope mounted in a Lockheed C-141 "Star Lifter" jet transport was developed for and became operational at NASA Ames in 1974. A moveable door and aperture tracked the telescope elevation to provide open-port viewing. The telescope is a "bent Cassegrain" configuration: light from the secondary was reflected from a tertiary to pass through the telescope-supporting spherical air-bearing and on to the focal plane instrument in the pressurized cabin. The gyro/star-tracker system achieved a pointing stability of 0.25 arc seconds RMS. During its 21-year lifetime, the KAO enabled observations ranging from 0.3 μm to 1.6 mm, made with over 50 different instruments provided by 33 different instrument teams. Some KAO science highlights: discovery of the rings of Uranus; measurement of intrinsic luminosities of Jupiter, Saturn, and Neptune; discovery of water in Jupiter's atmosphere; explorations of a major new ISM component - photodissociation regions; discovery of over 70 spectral features arising from atoms, ions, molecules, and grains; discovery of star-forming cores in Bok globules; discovery of far infrared luminosities of normal galaxies comparable to their visible luminosities; measurement of Fe, Co, Ni, and Ar produced in supernova SN1987A; first detection of astronomical far-infrared lasers; and discovery and identification of spectral features from potentially prebiotic polycyclic aromatic hydrocarbon molecules in the ISM.

Stratospheric Observatory for Infrared Astronomy - SOFIA: The 2.7 m SOFIA telescope is installed on a full pressure bulkhead aft of the wing in a Boeing 747SP aircraft. The fuselage behind the bulkhead is unpressurized. A moveable door and aperture provide an open port for the telescope, as on the KAO. The telescope is supported on a spherical

hydraulic bearing through which infrared and visible beams pass to the focal plane instrument and guiding camera. SOFIA science will include studies of the Galactic Center, ISM processes, star formation, and the solar system. Early science flights are scheduled to begin in 2009.

The Early Spread of the Telescope in Asia
Zoomers, Henk
Asian Historical Consultancy

After the first demonstration of the newly invented telescope by the Dutchman Hans Lipperhey in The Hague in September 1608 a quick spread of this new instrument in Europe occurred. Already half a year after this demonstration a telescope was in the possession of the Dutch States General, Stadtholder Prince Maurits, the French King, his Prime Minister, the Archduke of Austria and Pope Paul V. With an improved version Galilei Galileo managed to observe the satellites of the planet Jupiter in 1609. At the time of the demonstration a Siamese embassy sojourned in The Hague, being the first Siamese embassy to Europe. Probably they have been the first Asians ever to have seen (through) a telescope. The first formal presentation of the telescope in Asia occurred in Japan, when in 1613 captain John Saris of the English East India Company presented a telescope to the shogun. With the depiction of Dutch VOC employees in Deshima by Japanese artists during the 17th-19th century the telescope obtained iconographical dimensions together with the clay pipe. The Japanese were rather fond of the telescope, both as a scientific instrument and as a spyglass.

China is one of the earliest countries for the development of astronomy. The observatory on the city wall in Beijing, the Imperial Observatory of both the Ming and the Qing Dynasties is one of the oldest astronomical observatories in the world and can still be visited present-day. The Chinese Emperor also made use of the astronomical knowledge of the Jesuits, who demonstrated the superiority of western astronomy over the Chinese and Muslim astronomers. Jesuits like Ricci, Schall and Schreck (student of Galileo) used their knowledge and prestige to maximalise their opportunities to convert Chinese to the Catholic faith. On the other hand Dutch VOC reports from the first half of the 17th century suggest that rulers and/or high dignitaries in Lanchang (Laos) and Burma praised the telescope for the greater part as an object of amusement.

Contrary to these Southeast Asian countries Siam (present-day Thailand) in historical perspective

showed an intrinsic interest in astronomy. Two Siamese kings showed a personal interest in using the telescope for scientific reasons: King Narai (r. 1656-1688) and King Mongkut (1851-1868). Already as a prince King Narai ordered telescopes from the Dutch East India Company, who possessed a factory in the capital Ayutthaya. When France tried to gain a dominant position in Siam in the 1670's and '80's French Jesuits provided their astronomical knowledge to underline the French aspirations. Several drawings, present at the Bibliotheque National, and engravings in the travelogue of Father Tachard provide a clear view of their scientific activities in Siam. King Mongkut is honored in modern Thailand as the father of modern science and technology. He advocated the use of Western science over the indigenous superstitious beliefs of his astrologers. In 1868 amidst the presence of the British Governor from Singapore and a party of French astronomers and scientists he watched in Prachuap Khiri Khan province a total solar eclipse, which he had calculated two years earlier. His calculations proved accurate but during his sojourn he contracted malaria from which he died after he returned to the capital Bangkok, being probably the first royal victim of astronomical aspirations.

Galileo and the Birth of Science
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Universidad de Sonora

In this work I will argue that Galileo can be considered to be the person most responsible for the birth of science as we know it. It is indeed hard to think of anyone before him able to grasp better the true meaning of what it is a physical theory, the value of experiments and observations, as well as the importance of precise measurements and measuring devices. He not only understood the importance of science as a means to study nature and defend it the best way he could, but also excelled in its practice throughout his life, even under extremely difficult circumstances. The invention of the telescope in Holland in 1608 was a real blessing to Galileo, who eagerly converted it in a discovery machine of celestial objects, publishing his main results in his *Starry Messenger*, just a few months after becoming aware of the invention.

A Focusing Telescope for Gamma-ray Astronomy
von Ballmoos, Peter
CESR

Since the wavelength of nuclear gamma-ray photons is two to three orders of magnitude shorter than the distance between atoms in solids, astrophysicists are used to accept that it is "impossible to reflect or refract gamma-rays". Consequently, the telescope concepts in nuclear astrophysics do not employ mirrors or lenses; they are based on inelastic interaction processes making use of geometrical optics (shadowcasting in modulating aperture systems such as coded masks) or quantum optics (kinetics of Compton scattering). These instruments are now reaching the physical limits for space missions and have lead gamma-ray astronomy to an impasse where "bigger is not necessarily better". Improvements in the sensitivity of an instrument can usually be obtained by a larger collection area - in the case of traditional gamma-ray telescopes this involves a larger detector surface. However, since the background noise is roughly proportional to the volume of a detector, a larger photon collection area is synonymous with higher instrumental background. The sensitivity is thus increasing at best as the square root of the detector surface. This mass/sensitivity dilemma can ultimately only be overcome if gamma-ray astronomy finds a way of achieving what virtually all branches of astronomy have accomplished since Lippershey's invention 400 years ago: the focusing telescope. With the development of a Laue Lens we have taken up the challenge of a focusing gamma-ray telescope. In our Laue lens, gamma-rays are focused from the large collecting area of a crystal diffraction lens onto a very small detector volume. As a consequence, the background noise is extremely low. We present the principle of the Laue lens, the first astronomical light obtained with such a lens during a stratospheric balloon flight, and the state of the art in the development of diffraction optics. The results of this R&D program have opened the perspective of a focusing gamma-ray telescope operating in space, with a lens and detector situated on two formation flying spacecraft. With its unprecedented sensitivity, angular- and energy-resolution, a mission featuring a Laue lens addresses a wide range of fundamental astrophysical questions such as the life cycles of matter and the behavior of matter under extreme conditions.
