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COMMISSION 9: INSTRUMENTATION AND TECHNIQUES

(INSTRUMENTATION ET TECHNIQUES)

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THE PROGRESS IN TELESCOPES, INSTRUMENTATION AND TECHNIQUES

1. Introduction

From July 1, 1999 to June 30, 2002 is a special triennial period between 20th century and 21st century. Also it is an extremely unusual period in telescopes, instrumentation and techniques for having obtained unprecedented achievements. Eight 8-10m telescopes including four VLT units, two Gemini, Subaru and HET telescopes began their science operation during this period. Until now the total number of 8-10m telescopes, which have run for astronomical observation, reached ten. Other three 8-10m telescopes have been developed and will be completed in 2003 and 2004. During these three years many instruments were completed, improved or have been developed for these and other telescopes. These instruments are cameras with various image resolution and spectrographs (spectrometers) with various spectrum resolution and work at different wavebands. Except some telescopes with special type or use, for most telescopes the working wavebands are 0.3 - 28 micron. Many instruments are used for both image and spectrum in one. And many spectrographs are multi-object by using multi-slit or optical fiber. Almost all of these instruments are the first generation instruments. They will be improved or replaced by the next generation instruments. The new techniques especially adaptive optics have been already used successfully in most of these telescopes and other telescopes in near infrared waveband. By using larger ground-based telescope not only more light energy could be collected but also the higher resolution can be obtained. Another great achievement is that interferometry has been successful. It means the stellar fringe has been obtained in near infrared waveband, by Keck I and II, and by two unit telescopes of VLT. During this period, many other telescopes with apertures less than 8m, and a part of them with special type and use were completed or have been developed. Based on the successes of these large telescopes and adaptive optics, developments of the Future Giant Telescopes (FGT) with 30-100m aperture have been put forward. The following is the outline of these progresses.

2. Telescopes, Instrumentation and Techniques being Operated and Developing

Keck I and II: They are two 10m telescopes located at Mauna Kea, U.S.A., operated by the California Institute of Technology, the University of California and NASA, U.S.A.. Before this triennial period Keck I and II began science observations in May 1993 and October 1996 respectively. The most important characteristic of these telescopes is their segmented primary mirror. It consists of 36 hexagonal submirrors. The co-surface measuring, maintaining

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and calibration method for such a segmented primary mirror and the fabrication method of off-axis submirror are two key techniques. The most important meaning of the success of Keck I and II telescopes is that it create the possibility to build the even much larger telescopes. During this period the main progress of Keck I and II telescopes are: (1) Many instruments were commissioned: LWIRC- Long Wavelength Infrared Camera, NIRSPEC- Near Infrared Spectrometer, ESI- Echellette Spectrograph and Imager, DEIMOS- Deep Extragalactic Imaging and Multi-Object Spectrograph, and NIRC 2- Near Infrared Camera 2. Some instruments were refurbished or upgraded: LWS- Long Wavelength Spectrometer, LRIS-B- Low Resolution Imaging Spectrometer: Blue Side Upgrade, and HIRES- High Resolution Echelle Spectrometer. (2) The adaptive optics (AO) loops have been closed in Keck II telescope on February 5, 1999 and in Keck I on December 13, 2000. Diffraction-limited images of celestial bodies have been obtained in near infrared wavebands. The Strehl ratio is about 0.3 at H waveband. Each adaptive optics system includes a deformable mirror and a tip-tilt mirror. The deformable mirror has 15cm diameter and 349 actuators. Besides this, on December 23, 2001 the Laser Guide Star was tested successfully in Keck Observatory. It used a 20-watt dye laser to illuminate a diffuse layer of sodium atoms 95km above the Earth's surface and obtained a 9.5 magnitude artificial guide star. (3) Keck interferometer array including Keck I and II telescopes and four 1.8m telescopes. The largest base line of it is 140m. Keck I and II, separated 85m, were combined for the first as an interferometer on March 12, 2001. The starlight reached two Kecks, AO systems on Nasmyth platforms removed the atmospheric distortion for two light beams respectively then starlight through two coudé trains, the delay line finally to the combined focus. During March 12 to 14, 2001 fringes were obtained for about 20 stars.

VLT- Very Large Telescope: It consists of four 8.2m telescopes located at Paranal, Chile, operated by European Southern Observatory (ESO). The most important characteristic of VLT may be that there could be formed a big interferometry array VLTI which includes four 8.2m telescopes and three 1.8m movable telescopes. The largest base line of this array is 200m. The primary mirror of VLT is a monolithic thin mirror with only 17.5cm in thickness. In 1980's, ESO developed thin-mirror active optics and the relevant New Technology Telescope (NTT). It is one of the key techniques for obtaining excellent image quality for VLT and other monolithic thin mirror telescopes. The first light of four VLT unit telescopes were from May 1998 to September 2000. During the period from July 1, 1999 to June 30, 2002 besides the last two unit telescopes have been assembled and integrated in site, the other main progress are: (1) In 1998 the instruments were only FORS1- Focal Reducer/Low Dispersion Spectrograph and ISAAC- Infrared Spectrometer and Array Camera. Many instruments were first light or commissioned in this triennial period. They are: FORS 2, UVES- UV-Visual Echelle Spectrograph, CONICA- Near-Infrared Imager and Spectrograph, VIMOS- Visible Multi-Object Spectrograph, and FLAMES- Fibre Large Array Multi Element Spectrograph. The others NIRMOS- Near Infrared Multi-Object Spectrograph, CRIRES- High-Resolution IR Echelle Spectrometer, VISIR-Mid Infrared Spectrometer/Imager, and SINFONI- Single Far Object Near-IR Investigation are under developing now. (2) NAOS- Nasmyth Adaptive Optics System was first light on November 25, 2001. There are 185 actuators for deformable mirror and a tip-tilt mirror in NAOS. Together, they should permit to obtain a Strehl ratio up to 0.70 in K-band, depending on the actual seeing. (3) On October 29, 2001, Antu and Melipal, two of the four 8.2m VLT unit telescopes, separated 103m were linked to obtain the stellar interferometry fringes for the first time. And during this triennial period the interferometry of whole VLTI have been developed rapidly.

Gemini: It includes two 8.1m telescopes, Gemini North located at Mauna Kea, U.S.A. and Gemini South located at Cerro Pachon, Chile. The partnership of Gemini includes U.S.A., U.K., Canada, Chile, Australia, Argentina, and Brazil. Gemini North and Gemini South were first light in March 1999 and December 2000 respectively. The primary mirror of Gemini is a monolithic thin mirror. Gemini telescopes were elaborated for infrared waveband and its most important characteristic is the excellent infrared performance. During July 1, 1999 to June 30, 2002 period, besides South telescope to be assembled and integrated in its site, the main progress are: (1)The following instruments were delivered: GMOS (North)- Gemini Multi-Object Spectrographs, GPOL- Gemini Facility Polarisation Modulator, T-ReCS- Thermal-Region Camera and Spectrometer, and Phoenix- High Resolution Spectrometer. The others, GMOS (South), Michelle- Mid-Infrared Imager and Spectrometer, NIFS- Near-IR Integer Field Unit Spectrograph, NIRI- Near-IR Imager with Grism Spectroscopy, bHROS- bench-mounted High-Resolution Optical Spectrograph, GNIRS- Gemini Near-IR Spectrograph, NICI- Near-IR Coronagraphic Imager, Flamingos-I- Imager and Multi-object Spectrometer, and CIRPASS- IFU (integral field unit) Spectrograph are under developing, most of them will be commissioned in late 2002 and 2003. (2) At first the University of Hawaii's adaptive optics system Hokupa'a was installed on Gemini North telescope. During the triennial period the Altair, Gemini North adaptive optics system has been developed and it will be delivered to Gemini North in 3rd quarter 2002. Altair is a NGS/LGS AO system, it uses a 177-element continuous facesheet deformable mirror and a tip-tilt mirror.

Subaru: It is a 8.2m telescope operated by Japan and located in Mauna Kea, U.S.A.. Subaru was first light in December 1998 and has been offered for science open use since December 2000. The primary mirror of Subaru is a monolithic thin mirror. During July 1, 1999 to June 30, 2002 period the main progress of Subaru are: (1) Seven instruments were first light in 2000. They are: IRCS- Infrared Camera and Spectrograph, CIAO- Coronagraphic Imager with Adaptive Optics, COMICS- Cooled Mid Infrared Camera and Spectrometer, FOCAS- Faint Object Camera and Spectrograph, Suprime-Cam- Subaru Prime Focus Camera, HDS- High Dispersion Spectrograph, and OHS- OH Airglow Suppression Spectrograph. (2) The Subaru Adaptive Optics System is a 36 elements curvature sensor system with a bimorph deformable mirror and a tip-tilt mirror. This AO system with IRCS at K-band has seen first light on December 1-3, 2000.

HET- Hobby-Eberly Telescope: The equivalent aperture of this telescope is 9.2m and located in McDonald Observatory, U.S.A.. It is operated by the University of Texas and the Pennsylvania State University, U.S.A. HET is a tilted Arecibo-type telescope with a fix-elevation segmented spherical primary mirror and focal surface tracker. In addition to the design of its spherical aberration corrector, it also become a model for other spherical primary mirror telescope. The cost of HET is only about $13.5 million, less than one sixth of other telescope with the same aperture. But it has some rather restrictions in performance and use. On October 1, 1999 HET ended commissioning and entered science operation. During this triennial period the main progress are: (1) The alignment and maintaining systems of primary mirror and the focal surface tracker were improved. (2) In April 1999 the first instrument, LRS- Low-Resolution Spectrograph, was first light. It rides on the tracker at prime focus. In 2001 other instruments HRS-High-Resolution Spectrograph and MRS- Medium-Resolution Spectrograph were commissioned. HRS and MRS are optical fiber-fed and located in the HET "basement".

Even account to the time of beginning science operation is about one year or more later than the first light. All above ten 8-10m telescopes with their most of the first generation instruments have been operated for astronomical observation. Looking back from 1609 Galileo inventing the astronomical telescope to 1993 through 384 years, there were only two astronomical telescopes with aperture larger than 5m: Russia 6m telescope and U.S.A. 5m Hale telescope. But from 1993 to now only nine years ten 8-10m telescopes have operated for astronomy. How great progress this is! Besides above telescopes other three 9.2-11.8m telescopes are being developed now:

LBT- Large Binocular Telescope: It includes two 8.4m primary mirrors mounted in same mounting with 14.4m center-center separate. The partners are many universities and institutes of U.S.A., Italy, and Germany. It will be installed in Mt. Graham, Arizona, U.S.A.. Using combined mode, the equivalent in light power of this telescope is a 11.8m telescope. And using interferometry mode, the resolution of this telescope is a 22.8m telescope. LBT uses borosilicate honeycomb primary mirror with 1.142 very fast f-ratio. In December 2001 the telescope structure completed the pre-erection in Milan, Italy. It was shipped to Arizona in mid-2002. As of August 2002, the first primary mirror is being polished and the second is being cleaned out. Also its instruments are under developing now. First light (only one primary mirror) will occur in the spring of 2004.

GTC- Gran Telescopio Canarias: This is a 10m telescope, located in La Palma, Canary Island, Spain, operated by Spain, Mexico and U.S.A.. The primary mirror of GTC is segmented-mirror based on Keck design. Many parts of telescope have been completed. First light is planed for 2003.

SALT- Southern African Large Telescope: This is a 9.2m telescope, located in South African Astronomical Observatory, operated by South Africa and its German, Polish, American, New Zealand and U.K. partners. It is based on the Hobby-Eberly Telescope (HET) design. It is going to be completed in December 2004.

Account to the time of beginning science operation is about one year later than the first light. Up to 2005 or 2006 there will be thirteen telescopes with aperture more than 8m to operate for astronomy in the world.

Other telescopes, with aperture more than six meter or with some special features or use, completed or under constructed during this triennial period also are mentioned:

Multiple Mirror Telescope (MMT) Conversion: This is a joint facility of the Smithsonian Institution and the University of Arizona, U.S.A.. It replaced the original MMT to be installed in its enclosure. The primary mirror of it is a 6.5m borosilicate honeycomb mirror with 1.25 fast f-ratio. First light was achieved on May 17, 2000. Most of instruments have been delivered or will be delivered in 2002.

Magellan Project: This is a collaboration project between the Observatories of the Carnegie Institution of Washington and four universities of U.S.A.. It includes two 6.5m telescopes located on Las Campanas Observatory, Chile. The primary mirrors of Magellan Project are identical with the MMT Conversion. The Walter Baade telescope, one of these two telescopes, was first light on September 15, 2000. First light of another Landon Clay telescope is expected in 2002. Six of seven instruments of Baade telescope have been available or will be available in 2002.

LAMOST- Large Sky Area Multi-Object Fiber Spectroscopic Telescope: This is a China telescope, will be located in Xinglong Station, China. It is a special reflecting Schmidt telescope with 4m aperture and 5 degrees field of view. In tradition such an optical system is impossible, it is realized by changing the mirror shape in real time by using force actuators. The main work of LAMOST is extensive spectroscopic observation, 4000 optical fibers are going to be put on its focal surface. Now it is being developed and first light is expected in 2005.

VISTA- The Visible and Infrared Survey Telescope for Astronomy: This is an U.K. 4m telescope, will be located in Paranal, Chile to survey the southern celestial hemisphere. In VISTA there are an IR camera with 1sq degree field of view working at z, H, K wavebands and an optical camera with 2.25sq degree field of view working at u', g', r', i', z' wavebands. In July 2002 contract have been placed for 16 IR 2k by 2k detectors and primary mirror. Observing will begin in early 2006. First surveys will be completed within 12 years.

SOAR- Southern Astrophysical Research Telescope: This is a 4.2m telescope work at 0.3-2.5 micron, located at Cerro Tololo Interamerican Observatory (CTIO), by a partnership between National Optical Astronomy Observatories, two universities, U.S.A. and the Country of Brazil. It hope to pursuit of the best quality images of any 4m class telescope.

LZT- The Large Zenith Telescope Project: This is a 6m telescope project. It uses a rotating liquid (in general, mercury) to form a paraboloid mirror for the telescope. It is a collaboration between UBC, Laval University, Canada, and the Institut d'Astrophysique de Paris, France. Several 3m-class liquid mirrors have been built for different uses and one of them has given the diffraction-limited image. Now this 6m liquid mirror telescope is being developed. It is restricted to observe a moderate area round the zenith. But it is cost-effective.

During this triennial period the Hubble Space Telescope (HST) has two servicing missions: 3A in December 1999 and 3B in March 2002. In 3B mission the Advanced Camera for Surveys (ACS) which covers the ultraviolet to the near IR (120 - 1000 nm) is installed. The ACS increases the discovery efficiency of the HST by a factor of ten.

SOFIA- The Stratospheric Observatory for Infrared Astronomy is a 2.5m IR and submillimeter telescope loaded by a Boeing 747 SP aircraft. It is expected to begin flying in the year 2004.

SIRTF- The Space Infrared Telescope Facility is a 0.85m telescope, works at 3.6-180 micron waveband, which will be launched in January 2003.

FIRST- The European Far Infrared Space Telescope is a 3.5m telescope, works at 60-670 micron, which will be launched in 2007. Since these space telescopes have beyond the range of Commission 9 here only give a very simple description.

3. Future Giant Telescopes and Techniques

Today by using 8-10m telescopes and HST some events in early universe have been observed. Also one hundred Jupiter-like planets have been found by these and other telescopes. These stimulate the astronomers and popular people strongly to hope to observe more events in early universe including the first generation of galaxies and stars to shine in the dark universe i.e. to see the dawn of modern universe, to research the star formation, to observe the region near nucleus of the Galaxy and other galaxies, and to explore the earth-like planets in nearby stars. Telescopes much larger than existent generation 8-10m telescopes and 2.4m HST are needed for these researches. Technically, the success of segmented-mirror telescopes Keck I and II created a possibility to build much larger telescopes, and the progress of adaptive optics showed the diffraction-limited image could be obtained in ground-based telescopes at least in IR waveband. By using larger ground-based telescope not only more light energy could be collected, but also the higher resolution can be obtained. Thus the studies of Extremely Large Telescope (ELT) or recent called Future Giant Telescope (FGT) have already become one of the most active areas in observational astronomy and astronomical technology. Since the redshift $z = 5 - 30$ for first generation galaxies and stars and in general the star formation region is surrounded by dense dust so IR still is the most important waveband. FGT and Next Generation Space Telescope (NGST) should still be optical/IR telescopes. Space-based observation has extreme dark back ground, whole waveband, and could obtain diffraction-limited image in the whole field of view. But in the same technique stage ground-based telescope could have larger aperture than the space-based telescope, could match higher resolution spectrometer (spectrograph) and in some waveband with adaptive optics could obtain higher image resolution. Ground-based telescope and space-based telescope are always complemental. Existent 8-10m ground-based telescopes and 2.4m HST work complemental. 30-100m FGT and 6-8m class NGST will work in complemental action also. Many projects of FGT have been put forward, the science goal and configuration have been researched, the preliminary optical design, structure analysis and design have been done, the methods for fabricating of hundreds and thousands submirrors have been considered. The main projects of them are: OWL- OverWhelmingly Large Telescope, 100m spherical primary mirror, by ESO; CELT-California Extremely Large Telescope, 30m aspherical primary mirror, by the University of California and the California Institute of Technology, U.S.A.; GSMT- Giant Segmented Mirror Telescope, 30m aspherical primary mirror, by Association of Universities for Research in Astronomy (AURA), U.S.A.; Euro 50 - a 50m aspherical primary mirror telescope by Sweden, Spain, Finland, and Ireland; CFGT- Chinese Future Giant Telescope, 30m aspherical primary mirror by China; NGCFHT- the Next Generation Canada-France-Hawaii Telescope etc.. In order to build FGT the co-surface measuring, maintaining and calibration methods for segmented-mirror, which consists of hundreds even thousands submirrors, should be researched. Also the method for fabricating a lot of submirrors, which are small and the surfaces of them are asymmetric but asphericity is small, should be researched.

One should never forget the importance of instruments in telescope. Also one should never forget the importance of detectors in instrument, especially the high performance and large format IR detectors.

During July 1, 1999 to June 30, 2002 period techniques have great progress, among them the most important two are adaptive optics and interferometry. Adaptive optics has been used successfully in Keck telescopes, VLT and many other telescopes. In the next stage to develop the multi-conjugate adaptive optics is important. The interferometry has been already obtained preliminary success in Keck array and VLTI. It is sure that the whole VLTI array and Keck array will be successful and many astronomical results will be obtained in the near future.

4. Explanation

Above materials are from relevant web pages and 2000 SPIE Astronomical Telescopes and Instrumentation Conferences relevant Proceedings. Also readers could refer to 2002 SPIE Astronomical Telescopes and Instrumentation Conferences Proceedings, but since these proceedings have not been published I have not referred to them when I wrote this triennial report.

Commission 9 includes two Working Groups: the Working Group on Sky Surveys and the Working Group on Detectors. The triennial reports of these WGs are shown in the following pages.

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