Telescope Revolution

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Abstract

The scientific and technical challenges facing the astronomical community during the next decade are discussed within the framework of new technology and technical management issues. The astronomical telescope and instrument communities of industry, academia and government need to be prepared to meet the challenges of 21st century Astronomy. Emphasis is given to ground-based optical and infrared astronomy.

Introduction

A review of optics technology for new astronomical telescopes and instruments for ground and space missions is given. The investment by NASA in astronomical instruments and telescopes is large and the ground-based astronomical community must leverage off of these new developments if we are to provide state-of-the art astronomical data to the science community. Today we are experiencing a revolution in telescope and instrument technology and engineering. Current and planned missions for astronomical telescopes and instruments require advanced technology to be successful. The successful repair[2] of The Hubble Space Telescope (HST) demonstrated the importance of sustaining excellence in astronomical telescope and instrument technology and engineering. The current Space Infrared Telescope Facility will be a success because of an aggressive program in optical telescope and instrument engineering. The Next Generation Space Telescope (NGST), the Space Interferometer Mission (SIM) and the Terrestrial Planet Finder (TPF) Missions all require very sophisticated optics technology and optical engineering. Greater light gathering power and higher spatial resolution are required for many of the astronomical problems of the future.

New challenges are at hand. High resolution is becoming possible from ground-based instruments. Adaptive optics has begun to show its capability to upgrade conventional filled aperture telescopes, both for fast correction for atmospheric wavefront errors as well as slow correction for long-term optical errors in the basic optical system.

For still higher resolution imaging, interferometer projects are under way, the Georgia State University–NSF Interferometer on Mount Wilson, the JPL–NASA Palomar interferometer test bed, and the Keck–JPL–NASA Imaging Interferometer on Mauna Kea. All three, thanks in good part to adaptive optics, will be capable of resolution unattainable by single-aperture telescopes from the ground or space.

Higher resolution from telescopes in orbit is also a challenge for the future. The Hubble Space Telescope has shown the immense scientific payoff from high resolution. Astronomers quite naturally want to move to even higher resolution. The problem with

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bigger and better telescopes, whether ground-based or in orbit, is the rapidly rising cost of these Next Generation Space Telescopes. Larger single-aperture monolithic space-based optical systems are clearly too expensive. The nearly complete removal of the effects of the atmospheric turbulence will enable micro-arc-second spatial resolution from the surface of the earth using optical interferometers. This will increase the spatial resolution of astronomical observations by a factor of 10,000 in area over that currently achieved by HST.

The ground-based astronomical community must be more effective at integrating the advanced technologies being developed by other agencies, such as NASA and the Air Force. The National Aeronautics and Space Administration is spending over a hundred million dollars a year on technologies and engineering for astronomical telescopes and instruments. It is a challenge to the ground-based astronomical telescope and instrument community to make effective use of these developments to create ever more sensitive ground-based observatories for mankind to plumb the heavens. Teamwork between those aerospace companies developing technology for space astronomy and the academic/government communities of researchers is essential to create a cost-effective program for the future of ground-based astronomy.

Where are we going: The Decade report?

The Astronomy and Astrophysics Survey Committee was Co-Chaired by Professors Christopher F. McKee and Joseph H. Taylor, Jr. The process was to interview over an 18-month period nearly all of the members of the astronomical community. A preliminary report of the deliberations appears in a paperback book issued by the National Academy of Sciences the spring of 2000.

The primary science objectives outlined in this preliminary report are:

1. Determine the large scale properties of the universe
2. Study the dawn of the modern universe
3. Understand the formation and evolution of black holes of all sizes
4. Study the formation of stars and their planetary systems, and the birth and evolution of giant and terrestrial planets.
5. Understanding how the astronomical environment affects Earth.

Completion of these science objectives requires a program that integrates ground and space based telescope observations across the electro-magnetic spectrum from the X-Ray to the long-wave radio. Hence a very wide range of technology-complex instruments and telescopes are required to enable the recording of data valuable to science.

The committee felt that these science objectives are best pursued using several major initiatives and moderate initiatives. The major initiatives for the astronomical community during the next 10 years are shown in the table below. The first column identifies by name the initiative, the second column identifies ground or space, and the third column identifies the region of the electro-magnetic spectrum to be observed.

MAJOR INITIATIVES

The next generation Space Telescope:	Space	O/IR
Giant Segmented Mirror Telescope	Ground	O/IR
Constellation X Observatory	Space	X-ray
Expanded Very Large Array	Ground	Radio
Large Aperture Synoptic Telescope	Ground	O/IR
Terrestrial Planet Finder	Space	O/IR
Single Aperture Far Infrared Observatory	Space	IR/Sub-mm

The total cost for these Major Initiatives as estimated by the committee members (as provided in the "Advance Copy" of the Astronomy and Astrophysics in the new Millennium) to be around \$3.B. Two of the initiatives are for ground-based astronomy. These are Giant Segmented Mirror Telescope (GSMT) and the Large Aperture Synoptic Telescope (LAST).

The table below provides a tabulation of the moderate missions as provided in the Advance Copy of the Astronomy and Astrophysics in the New Millennium. This tabulation reflects only those telescopes and instruments that function on the ground.

MODERATE INITIATIVES

Telescope System Instrumentation Program (TSIP)
Advanced Solar Telescope (AST)
Square Kilometer Array (SKA) Technology Development
Combined Array for Research in mm-wave Astronomy (CARMA)
Very Energetic Radiation Imaging Telescope Array System (VERITAS)
Frequency Agile Solar Radiotelescope (FASR)
South Pole Submillimeter-wave Telescope (SPST)

Challenges for Telescopes

This new decade will witness the completion of several very large (6 to 10-meter clear aperture) optical and infrared telescope systems. Optimizing the performance of these giant telescope systems will occupy the energy of many astronomers and engineers this decade. Key to the success of these large telescope systems are the technologies of adaptive optics, control-structure interaction theory & application, large area focal planes, innovative instruments. Indeed many astronomers believe that very large aperture ground-based telescopes will be a requirement in the future for cutting edge, state-of-the art scientific research.

At least three groups are now working to create engineering visions and design approaches for a ground-based telescope in the 30 to 100 meters clear aperture diameter size. Segmented primary mirrors, adaptive optics, unique structures, innovative controls, large area focal planes, innovative imaging spectrometers and visionary planning characterize these telescopes. Older and more mature technologies will be tested at much larger scales. It is unknown how these technologies, well understood today at smaller scales, will "scale-up" to the job of a 100-meter class clear-aperture telescope. New inventions will be needed.

Challenges for Instruments

The design and construction of instruments for telescopes in the 8-meter clear-aperture and above class poses a special set of problems. These instruments are of a size and more complex than that of entire 4-meter telescopes that astronomers designed and built just a decade ago. The cost for each these focal-plane instruments ranges upwards of 5 to 7 million dollars during a 36-month hardware build cycle. This is about $5,000.00 per day expenditure rate. An interesting question is: do each of these new 8-meter class telescopes need a full complement of 1. Visible-light (silicon CCD) imaging spectrometer (at different dispersions), 2. Near infrared imaging spectrometer (at different dispersions), 3. Far-infrared imaging spectrometer (at different dispersions), 4. Wide-angle large-area focal plane imaging cameras, 5. Polarization analyzing apparatus, 6. High speed photometers, and etc. The answer must be no! We cannot afford it. Being smart about how instruments are selected for development is key to optimizing these large telescope apertures for the best scientific return.

Enabling Technology

The enabling technologies for ground-based astronomical telescopes and instruments can draw heavily from the technology being developed to enable the next generations of large space telescopes. For example the technology issues related to phasing a segmented mirror for space astronomy[3],[4],[5] have application to segmented ground-based telescopes. Wavefront compensation optimization is a maturing science and technology[6] . Materials and structures are important for ground-based telescopes as well as space-based telescopes[7]

Conclusions

Ground-based astronomy is at the dawn of a new age. Advanced technology has demonstrated that very valuable, cost-effective astronomical science can be completed using ground-based astronomical giant telescopes combined with innovative advanced technology. Much higher spatial resolution and longer integration times will be available for the next generation astronomy.

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[2] J. B. Breckinridge and H. John Wood The Hubble Space Telescope Repair Applied Optics, XXX, 1994

[3] D.C. Redding, et. al., Wavefront control for a segmented deployable space telescope, paper 4013-115 Proceedings of the SPIE Vol. 4013, page 546-558. , 2000 Munich Germany Astronomical Telescopes & Instrumentation 2000. Published by the International Society for Optical Engineering.

[4] M.R.Schulthess, et. al. Joint NASA and DoD deployable optics space experiment, paper 4013-34 Proceedings of the SPIE Vol. 4013, page 568-579. , 2000 Munich Germany Astronomical Telescopes & Instrumentation 2000. Published by the SPIE-The International Society for Optical Engineering .

[5] R. G. Paxman, T. J. Schulz and J. R. Fienup, Joint estimation of object aberrations using phase diversity, J. Opt. Soc. A 9, 1072-85 (1992)

[6] P. L. Wizinowich, Adaptive optical systems technology, 2000 Munich Germany Astronomical Telescopes & Instrumentation 2000., Published by the SPIE-The International Society for Optical Engineering .

[7] P. Diericks, Conference Chair, Optical design, materials, fabrication and maintainence, 2000 Munich Germany Astronomical Telescopes & Instrumentation 2000., Published by the SPIE-The International Society for Optical Engineering .