NOAO: Building the Future[1]

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Abstract

As the nature of astronomical research and the distribution of scientific funding change, the National Optical Astronomy Observatories (NOAO) will transform its programs to gain maximum advantage from new scientific capabilities. Moreover, the operation of 4-m class facilities in the era of new 8 to 10-m telescopes radically alters our mandate. NOAO will continue to enable top-ranked research at Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory and will support the US community's use of the Gemini Observatory. Over the past decade NOAO has revitalized its capabilities through the construction of new telescopes and instrumentation critical to enabling world-competitive research. NOAO is now transforming its program to enable science conducted on 8-m class telescopes in unique ways. NOAO will build instrumentation and telescopes for wide-field imaging and spectroscopy in both the optical and infrared to complement Gemini capabilities.

Key words: NOAO; Telescopes; Astronomical Instrumentation

1 Introduction

Discoveries in astronomy are most often stimulated by the introduction of new telescopes and instruments, i.e. by new ways of looking at the universe. While once a 4-meter was a world-class telescope, we now live in the era of 8 to 10-m facilities, an aperture that reveals a whole new universe (Fig. 1). In order that those of us who operate 4-m class facilities will continue to contribute significantly to scientific discoveries, we must change the way we do business.

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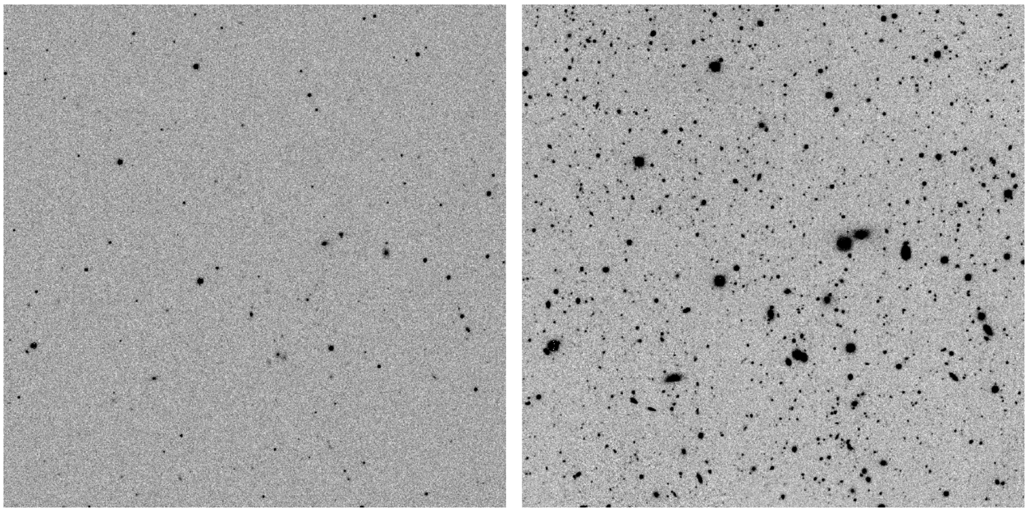

Fig. 1. Eight to 10-m telescopes reveal a whole new universe. The image on the left shows the spectroscopic limit of a 4-m telescope (R=23). That on the right is to the Gemini spectroscopic limit (R=26).

Over the next decade an impressive list of new astronomical facilities will be available worldwide. A total of fifteen optical-infrared facilities with apertures greater than 6.5-m will provide astronomers with many ways to get ground-based data. Moreover, NASA missions—e.g. HST, NGST, SIRTF, AXAF, Constellation-X—come with significant funding to the principal investigator for data analysis. The driver for us is no longer to enable science for those without their own facilities, but rather to enable world-class science through world-class telescopes and instrumentation. The best figure of merit may well be 'uniqueness times demand'.

The scientific challenges for the 21st century require, in most situations, limiting observations with 8-10 m facilities, like those of the Gemini Observatory. These new telescopes reveal a new view of the universe by probing deeper and with more resolution than previously possible. After the first few years of looking at known objects, astronomers must turn to new sources to answer the next level of critical questions. New objects must be revealed through new deep surveys, both imaging and spectroscopic. In addition to surveying for new objects, such surveys will revolutionize our studies. Astronomy will expand beyond the study of a few hundred objects for an astronomer—or even a few thousand—to one of millions. We will be able to consider the entire population of a large volume of space or to investigate essentially all of an entire class.

This is a particularly good time to be talking about the future of NOAO as we have just completed development of our long range plan for the next five years (full text and illustrations are on the WWW at http://www.noao.edu) and because American astronomy is undergoing its decadal review where strategic scientific priorities are thoroughly analyzed and future goals set. This paper will outline the likely direction of astronomical research over the next decade and will summarize the approach that NOAO will take to address these objectives.

2 Cosmic transformation

The goal for astronomy over the first decades of the 21^{st} century is to understand the transformation of the universe from a not-quite-smooth distribution of the very simple elementary particles in the Big Bang to the rich, complex world we see around us. The primary challenge is to understand how the objects that populate the universe are transformed over the lifetime of the universe and to determine what physical processes shape this evolution. To address these cosmic transformations astronomers must start with very basic questions: how were small density fluctuations in the Big Bang transformed into galaxies and clusters of galaxies; how are clouds of dust and gas transformed into stars; and how are disks around newly forming stars transformed into planets.

The past decade has seen critical advances in the determination of the local expansion rate of the universe combined with a suggestion that there may be a positive cosmological constant. The contribution of baryonic matter in the universe has been constrained. Over the next decade we will move from characterizing the geometry of the local universe to determining how the Universe's geometry has evolved since the Big Bang. To discover the processes that drive the evolution of the universe will require a multi-wavelength approach, large scale surveys to define well-chosen samples, and synoptic and interrupt-driven observations of transient phenomena.

The study of star formation will similarly undergo profound change. We now know that circumstellar accretion disks are the norm among forming stars of all masses and in all environments. The material to build planets surrounds all stars from their formation. The next decade will see new understanding of the patterns that characterize the main stages of stellar and planetary formation.

The current generation of 4-m telescopes, properly equipped for deep imaging and spectroscopic surveys, are well matched to Gemini-class telescope spectroscopic limits. For example, to quantify large-scale structure through bulk flows, observations of supernovae provide the best standard candles. The discovery of supernovae at $z \approx 0.1$ is best done with wide-field imaging on 4-m class telescopes with photometric follow-up on 8-10-m apertures. In addition, the large sample of supernovae discovered with 4-m telescopes requires 8-10-m spectroscopic follow-up to understand the physics of supernovae in a wide range of galactic environments.

3 The National Optical Astronomy Observatories

The scientific questions outlined in the previous section are a challenge to all of astronomy. The National Optical Astronomy Observatories plans to play a major role in providing research facilities for US astronomers and in leading the development of the next generation of groundbased telescopes.

NOAO is the national observatory of the United States of America. It is funded by the National Science Foundation and operated under cooperative agreement by the Association of Universities for Research in Astronomy. NOAO telescopes and instrumentation are used by professional astronomers and their students from research institutions throughout the U.S. Scientific programs enabled by NOAO are as broad as the interests of the more than one thousand scientists who use our facilities each year. Proposals from international investigators are accepted on equal basis to American scientists, as the goal is to enable the best science, no matter where the principal investigator is resident.

The mission of NOAO is to provide leadership in the establishment and operation of premier groundbased astronomical research facilities, to promote public understanding and support of science, and to advance all aspects of US groundbased astronomical research. NOAO operates two facilities for nighttime astronomy, Kitt Peak National Observatory, near Tucson, Arizona; and Cerro Tololo Inter-American Observatory, near La Serena, Chile. NOAO is the gateway for US astronomers to the Gemini Observatory.

Kitt Peak National Observatory marked forty years of discovery in 1998. The past four decades were celebrated in a supplement to Nature (vol 395, no. 3701, 1 October 1998) that highlighted scientific discoveries made through KPNO facilities. These discoveries included, among others, the first indication of dark matter through flat rotation curves for galaxies; the connection between the local density of galaxies and star formation, stellar populations and the morphology of galaxies (the Butcher-Oemler effect); the discovery of the void in Bootes that lead to the realization that some very-large-scale-structures in the universe are not likely in equilibrium.

4 The Transformation of NOAO

NOAO plans for the next decade are to continue to provide facilities on Cerro Tololo and Kitt Peak to carry-out forefront scientific research that does not need 8-m class telescopes, to enable 8-m science in a unique way, and take a lead role in ensuring the continued strength of US groundbased astronomy through the development of new large aperture facilities. In order to gain maximum scientific advantage from new capabilities, NOAO is transforming its program to include:

- The ability to schedule complex programs that require the use of more than one observatory, including the Gemini telescopes.
- The ability to commit substantial blocks of telescope time to individual programs, especially surveys.
- Instrumentation and telescopes for wide-field imaging and multi-object spectroscopy in both the optical and infrared to complement Gemini capabilities.

Over the past decade we have responded to changing scientific demands with continual renewal of our capabilities and through construction of new telescopes and instrumentation critical to enabling world-competitive research. The WIYN telescope, built on Kitt Peak with university partners, has demonstrated that Kitt Peak is a better 'seeing' site than previously thought. Astronomers now expect sub-arc second images and so we have undertaken rigorous thermal management of our domes, cut vents in the domes to allow flushing with ambient air, and cooled mirrors to get the best delivered image quality possible. We have built instruments with unique capabilities to provide leading edge research tools. Hydra, the pioneering multi-object spectrometer, and Mosaic, an 8K x 8K CCD imager, are now available at both CTIO and KPNO. Phoenix, a high resolution IR spectrometer, has revitalized capabilities previously only available with low-efficiency Fourier Transform systems.

NOAO has recently begun a revolutionary process of observing proposal review that will allow one proposal to be used for time at CTIO, KPNO, US time on Gemini, and NSF-sponsored time on the Hobby-Eberly Telescope and the MMT. NOAO is the gateway for US astronomers to the Gemini Observatory. Beginning in 2000 and for the next six years, NOAO will allocate through peer review 27 nights per year on each of the Hobby-Eberly Telescope and the MMT. One proposal to the NOAO observing proposal process will be all that will be required for a scientific program to propose to use the NOAO, Gemini, HET or MMT facilities. For example, an astronomer may want to quantify pre-main sequence mass infall rates with stellar mass. This program would require first wide-field imaging with Mosaic on the Mayall 4-m to survey molecular cloud complexes to select star forming objects of a certain range of ages, followed by wide-angle multi-object spectroscopy at WIYN to derive accurate ages and masses, before obtaining high resolution spectroscopy at Gemini to measure the mass infall rates. All three facilities would be accessed as an observing system with one proposal, without placing the following work in jeopardy by having to propose at each separate facility.

Groundbased telescopes will play a central role in the strategically important scientific research identified by the National Academy of Sciences Decadal Sur-

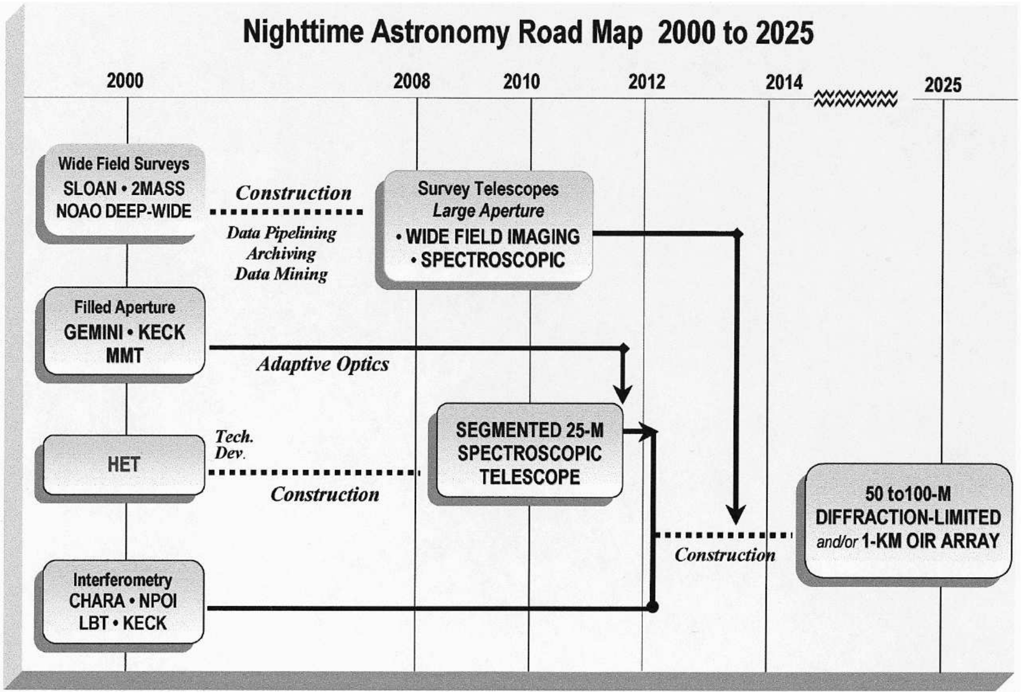

Fig. 2. A timeline for new groundbased astronomical facilities over the first 25 years of the 21^{st} century.

vey. Only groundbased telescopes have the ability to provide wide-field imaging, wide-field multi-object spectroscopy, high-resolution spectroscopy, high angular resolution imaging, and time coverage.

For groundbased astronomy the NOAO Long Range Plan outlines the construction of the following nighttime facilities by 2025 (see Fig. 2 for a timeline):

- *Two Wide-Field Telescopes* – with apertures of at least 6.5-m and 3^o field of view, in order to conduct deep imaging and spectroscopic surveys to explore such issues as the evolution of galaxies and the nature of dark matter; to define the population of the solar system, including both asteroids and Kuiper Belt objects; and to study variable objects, including supernovae
- *An Extremely Large Telescope (ELT)* – with an aperture on the order of 30-m to enable near-infrared spectroscopy to limiting magnitudes 10 times fainter than NGST.
- *The Maximum Aperture Telescope (MAXAT)* – which will have an aperture of 50-m or more and will achieve diffraction-limited imaging, and/or
- *The 1-km Optical-Infrared Interferometric Array* – for high angular resolution studies of stellar surfaces, active galactic nuclei, circumstellar environments, and reconnaissance of small bodies in the solar system.

During the next five years, NOAO in its nighttime program plans to:

- Complete construction of SOAR, a 4-m telescope in the southern hemisphere optimized for excellent image quality.
- Begin construction of two wide-field imaging and spectroscopic survey telescopes.
- Initiate development of technology for the Extremely Large Telescope and the Maximum Aperture Telescope.

Users of NOAO facilities have come to expect effective software to be supplied with the observing instrumentation, a resource that has proven to ensure quick and accurate data reduction and one that significantly decreases the time from observation to publication. Four factors will influence the next generation of groundbased data reduction software: very complex instrumentation, large format detectors and associated high data volume, the likelihood that astronomers will not actually be at the telescope taking the observations themselves, and the importance of ready access to survey data. NOAO will draw upon its expertise with the IRAF Project to implement software capabilities that will enable efficient data reduction and analysis through pipelining, data archiving, archive query, archive mining, and data distribution.