

***NOAO is developing plans for new telescopes that will increase angular resolution, areal coverage, and sensitivity by factors of ten.***

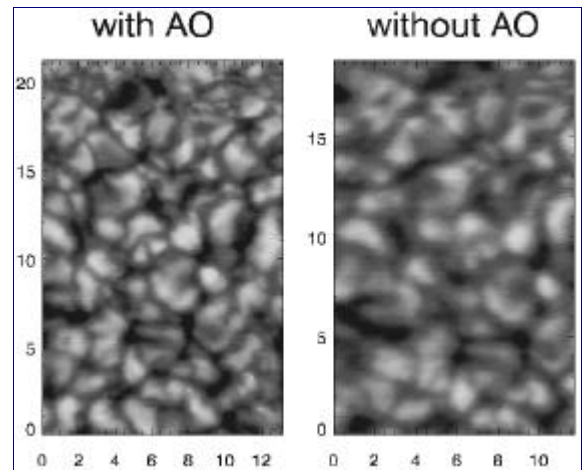
### ***New Construction: Solar Astronomy***

***The major new project in solar physics at NOAO will be the construction of a 3- to 4-m Advanced Solar Telescope (AST).***

When coupled to adaptive optics, the AST will be capable of breaking the 0.1 arcsec barrier in the visible and providing the resolution needed to analyze the active magnetic microstructure. The large aperture is required to provide the photon counts needed to follow changes on short time scales. Models suggest that many of the physical processes controlling atmospheric heating and magnetic field stability occur on scales of  $\sim 70$ - $100$  km or  $\sim 0.1$  arcsec, and that magnetic fibrils move at velocities of  $\sim 0.5$ - $0.7$  km s<sup>-1</sup> and have lifetimes of  $\sim 20$  minutes. Achieving high temporal and spectral resolution simultaneously with the necessary signal-to-noise (S/N) ratio requires a high photon flux, which in turn requires a large aperture telescope ( $\sim 3$  m), even for the Sun. It is unlikely that a solar telescope of such a large aperture will be deployed in space in the next two decades. In the visible, the AST will complement forthcoming missions such as SOLAR-B, which will have an aperture of 0.5 m and will operate over a wider field of view than the AST.

Critical diagnostics of the solar magnetic field in the low chromosphere and the corona reside in the thermal infrared, thereby adding a requirement for an all-reflective telescope and low-scattering optics.

During the next two years, the NSO, in collaboration with the solar community, will define the scientific requirements for the AST, a facility that was given a very high priority in the recent Parker committee report from the National Research Council. NSO will then develop a design, establish the technical feasibility of building a telescope that can meet the stringent requirements on image quality, and identify a suitable site, probably one located in a lake. The goal is to submit a proposal to the National Science Foundation in approximately three years.



### ***Adaptive Optics***

*As a necessary prelude to the AST, NSO has embarked on a program to develop adaptive optics (AO) for solar applications. Comparison of the images of solar granulation above—which were taken at 500 nm—shows the improvement offered by AO. The image on the left has been corrected with a low order AO system. The uncorrected image on the right is of a slightly different field but was obtained simultaneously.*

## ***New Construction: Nighttime Astronomy***

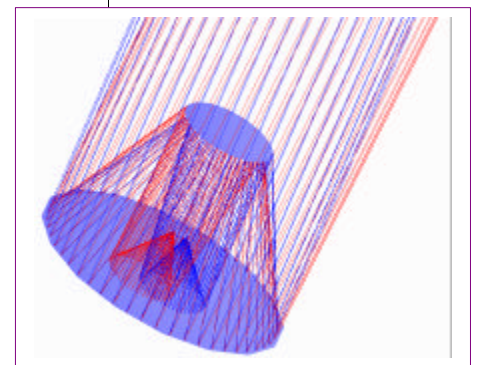
The Gemini telescopes, a project initiated at NOAO, will both be operational by 2002. What next for groundbased astronomy? More than 20 years elapsed between the start of construction on the NOAO 4-m telescopes and the first funding for the Gemini telescopes. That interval is clearly too long—too long to respond to scientific opportunities and too long to take advantage of rapidly developing technologies.

***An appropriate model is the one followed so successfully by the radio community: construction of a major new facility in each decade coupled with the parallel development of technology required for the facility to be built in the next decade.***

### ***Wide Field Telescope (WFT)***

Imaging and spectroscopic surveys of large areas of the sky to very deep limiting magnitudes will enable qualitatively new kinds of science. Characterization of the distribution of total mass through gravitational lensing and studies of the halo populations in nearby galaxies as tracers of galaxy evolution are but two examples of problems that are limited by the narrow fields and/or limited aperture of *all* existing telescopes. A modified Paul design has been developed by Angel and Dunham that can achieve a field of view of  $3^\circ$  in the optical and  $1.5^\circ$  in the thermal infrared with excellent image quality. With a telescope built to this design, it would be possible to map the entire visible sky in only a few days, making it well-suited to such problems as discovering *all* the Earth-crossing asteroids down to a diameter of 300 m. The telescope would be ideal for mapping dark matter and could locate *all* of the mass in a cone out to a redshift of  $z = 1$ . Every exposure would contain 30 supernovae with redshifts greater than  $z = 1$ . The telescope would also open a whole new domain for the study of time variable objects. NOAO, Steward Observatory, and Lowell Observatory will jointly develop the science requirements, devise concepts for the instrumentation, and prepare technical and funding proposals.

The growing numbers of imaging surveys—both on the ground and at a range of wavelengths accessible from space—will create an increasing demand for efficient spectroscopy of hundreds to thousands of objects per square degree. For example, to trace the evolutionary histories of galaxies (star-forming history; chemical evolution; merging and morphological properties) will require studying objects with a range of redshifts, masses, star-formation rates, morphologies, mean chemical abundances, and environmental density. Obtaining one percent statistical weight after each of these broad categories is divided into 3 – 5 bins will require spectroscopy of at least 500,000 galaxies. NOAO is exploring options to provide a spectroscopic survey capability that would enable observations of large numbers (1,000 – 10,000) of faint ( $\sim 22 - 24$  mag) objects over a large field of view ( $\sim 1.5^\circ$ ).



### ***Modified Paul design developed by Angel & Dunham***

*This three mirror optical design will provide excellent images over a  $3^\circ$  field of view. The primary mirror is 6.5 meters in diameter and has an  $f$ /ratio of  $f/1$ .*

The goal of these projects is to keep the construction costs low by using existing telescope mount and enclosure designs. New technology/design efforts will be kept to a minimum. The instrumentation and data handling/analysis/archiving aspects of the project will be very challenging and may prove to be more expensive than the telescope itself. *However, developing the technology to handle and mine large data sets is at least as critical in advancing astronomy as developing telescope technology.*

**Extremely Large Telescope (ELT) and Maximum Aperture Telescope (MAXAT)**

What is the future of groundbased OIR astronomy after the construction of this generation of 8- to 10-m telescopes? Over the next several decades there will be a premium on both high sensitivity and high angular resolution.

Groundbased astronomy must evolve to meet both needs. For fixed total cost, a large single dish telescope affords greater sensitivity and a larger field of view than does an interferometer, and both capabilities offer substantial advantages for cosmological studies. Interferometers provide the ultimate in angular resolution, which is critical for problems ranging from stellar physics to probing the central regions of active galaxies. Given the NASA commitment to develop interferometry in space, and based on our assessment of the scientific opportunities as well as on external advice, NOAO is focusing its own efforts on filled aperture telescopes.

The overall path toward larger telescopes will be determined by technical as well as scientific considerations: (1) an increase in aperture of a factor of 2, which has been typical of past telescope construction projects, is too modest to achieve the scientific goals of the 21st century and provides too small an incremental capability over the NGST; (2) engineering projects that advance the state of the art by a factor of 10 are likely to present unacceptable cost, schedule, and performance risks; and (3) the path chosen must also provide for pathfinder, planning, parallel, and follow-up observations required by NGST.



**30-m ELT**

*A 30-m telescope would provide unprecedented sensitivity for spectroscopy in the near-infrared.*

The MAXAT workshop sponsored by AURA identified the scientific role for 25- to 100-m telescopes: high sensitivity, high angular resolution imaging spectroscopy, with emphasis on infrared observations. Such a facility would enable spectroscopy of the faint sources that will be imaged by the Next Generation Space Telescope (NGST). An aperture of 50 m is the minimum required to obtain spectroscopy of all of the objects in the Hubble Deep Field. With a 50-m telescope, it would be possible to observe directly all stages of the star formation process from the infall of gas from the outer envelope onto the disk to the imaging of newly

**The projects for the next three decades that are being explored by NOAO are, in chronological order:**

- **Very Wide Field (~3°) Large Aperture (6.5-m more) Telescopes (WFT)** in each hemisphere to construct samples and select objects to the deep limiting magnitudes accessible with efficient spectrographs on Gemini-class telescopes
- **An Extremely Large Telescope (ELT)**, modeled on the design of the Hobby-Eberly Telescope, with emphasis on near-infrared-spectroscopy
- **The Maximum Aperture Telescope (MAXAT)**, which has as its goal diffraction-limited observations and an aperture of 50 to 100 meters

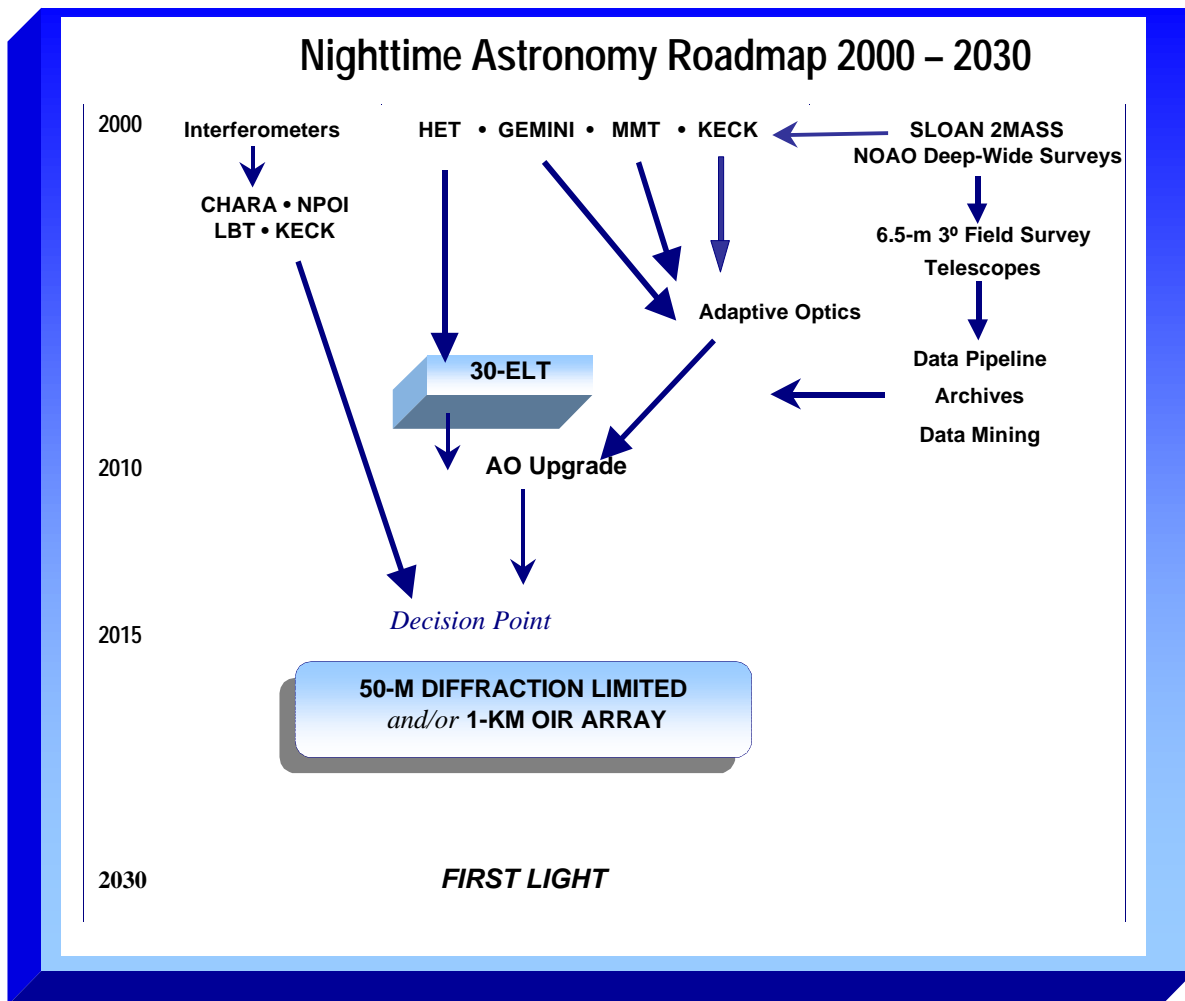
formed planets. Enough planetary systems would be within the reach of such a telescope that we could finally characterize the properties of giant planets and determine whether our solar system is unique or whether there are potentially many like it. At 100 m, it would be possible to observe Cepheids to a distance 100 times beyond that of Virgo, study supernovae to  $z = 10$ , and image white dwarfs in Andromeda.

**Critical issues in technology development for 25- to 100-m telescopes include the following:**

- **Site testing.** Identification of a dark site with superb image quality, excellent infrared characteristics, and a high percentage of photometric nights is mandatory. Sites in northern Chile, including both the MMA site and isolated mountain peaks nearby, need to be tested.
- **Adaptive Optics.** The signal-to-noise (S/N) ratio for background-limited observations of point sources scales as the square of the diameter of the telescope only in the case of diffraction-limited images. Construction of instruments for very large telescopes will also require small beam size and hence diffraction-limited images. To achieve the full potential of a MAXAT will require in all probability the implementation of multiple-laser guide star adaptive optics (AO), a capability currently under development but beyond the range of existing technology. Full AO correction will also be required to reduce source confusion.
- **Blank Fabrication.** The total area of glass required, even for a 30-m telescope, will exceed that of 10 Keck telescopes. New approaches to fabrication will be required to produce the glass for manageable costs and on an acceptable time scale.
- **Optical Fabrication.** The existing infrastructure in the optics industry is inadequate to meet the optical polishing requirements for even a 30-m large aperture telescope. While the processes involved are well established and have low risk, designs for the processing facility will be required.
- **Surface Control.** Methods must be established for sensing the positions of the mirror segments and for maintaining mirror figure for whole nights without recalibration.
- **Telescope Structure.** Design will be required to ensure that structural dynamic performance meets specifications.

**Prerequisites for construction of very large (>25-m) telescopes:**

- *Continuing development of the scientific case, taking the results from the current generation of large telescopes, deep surveys, and NGST into account.*
- *Development of the required technologies.*
- *Partnerships between NOAO, the independent observatories, and the university community, to engage the best talents in these challenging projects.*



Given the level of technology development required, it would be prudent to move to construction of MAXAT, which we will define here as a 50- to 100-m telescope, only after the construction of a 25- to 30-m telescope.

**The option that appears most promising for this next step is the Extremely Large Telescope (ELT).** The ELT is a 30-m version of the Hobby-Eberly Telescope (HET), and this option will be explored in depth by NOAO in collaboration with the community, and particularly with the University of Texas. Such a telescope with seeing-limited images would offer sensitivity gains of a factor of 10 over the NGST for near-infrared spectroscopy at resolutions greater than 10,000. Because it operates at fixed altitude and tracks only in azimuth, it offers some clear simplifications in what will be a very challenging project. Working with its university collaborators and with industry, NOAO will define the technology development program and seek funding for it.

***New technologies will determine the future of ground-based astronomy.***

*Existing facilities are developing technologies for interferometry, adaptive optics, surveys, data handling, and large filled apertures. These experiments will make it possible to proceed with confidence to extremely large filled aperture telescopes and to interferometers with large aperture component telescopes spaced over very long baselines.*

## **Interferometry**

While our current emphasis is on filled aperture telescopes, we are continuing to explore options for interferometry, because distributed aperture on the ground may very well become a high priority for the community. Stephen Ridgway, in collaboration with François Roddier (Univ. of Hawaii), has undertaken an initial effort toward planning a next generation optical interferometry facility, which would follow the small facility interferometers now starting operations (CHARA, for which Ridgway serves as co-PI and Technical Manager, and NPOI), and complement the major but limited VLT and Keck interferometer projects now under development. Several steps are planned. A small grant will be sought, with possible limited additional institutional support, to carry out a one-year planning study. This will begin with a small workshop to explore technical options and scientific opportunities and priorities, and to lay the foundations for a proposal to fund a substantive design and costing effort. One or more demonstration projects are under consideration, including a prototype unit telescope and a demonstration of interferometric fiber linkage of two large, AO equipped telescopes. Gemini North and CFHT are one pair of candidates for such linkage. When the technology development for both interferometry and large filled-aperture telescopes is more advanced, we will be in a much better position to decide between MAXAT and a large interferometric array as the next major groundbased initiative.

## **Software**

A new observing system, matched to the challenges of the next decades, depends not only on facility and instrumentation development, but also on our ability to develop the software tools critical to enabling key elements of the system. NOAO has a rich history of leading community efforts to develop end-to-end software—from data acquisition, to on-site processing, to sophisticated analysis tools. We regard continuing and reshaping this effort to match the needs of the next decade as one of our highest priorities.

Success will require careful assessment of the scope of each of these system components and analysis of how to structure the NOAO effort. Specifically, over the next year through consultation with colleagues in astronomy, other scientific communities, and the private sector, we will define:

- The number and skills mix (programming, scientific oversight, strategic planning and management) required of a core software group;
- How best to combine NOAO strengths with those extant in the university community, existing NASA data centers, and the private sector;
- What mix of specialized software developed in-house and modification of existing, commercially-available packages will best meet our needs;
- How to ensure that the framework adopted for software admits ready incorporation of packages developed in a variety of system environments.

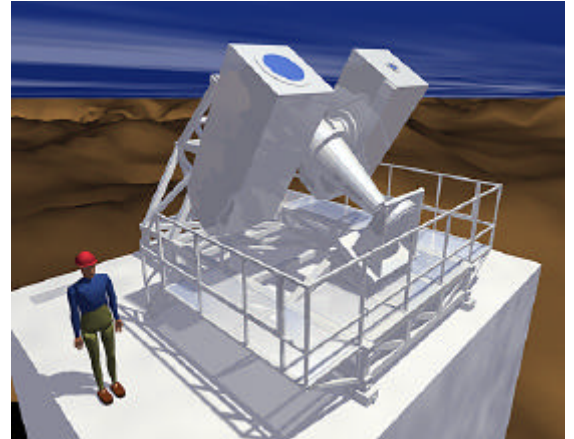
## **Key components of software infrastructure in the NOAO Observing System:**

- *Tools for enabling efficient queue and interrupt-driven schedules matched to service and target-of-opportunity observing*
- *Protocols for streamlining data acquisition and calibrations*
- *Standardized pipeline reduction tools*
- *Efficient mechanisms for assessing and assuring data quality*
- *Efficient mechanisms for archiving pipelined data and catalogs*
- *Tools for querying archived data and catalogs*
- *Tools for “mining” large image databases*

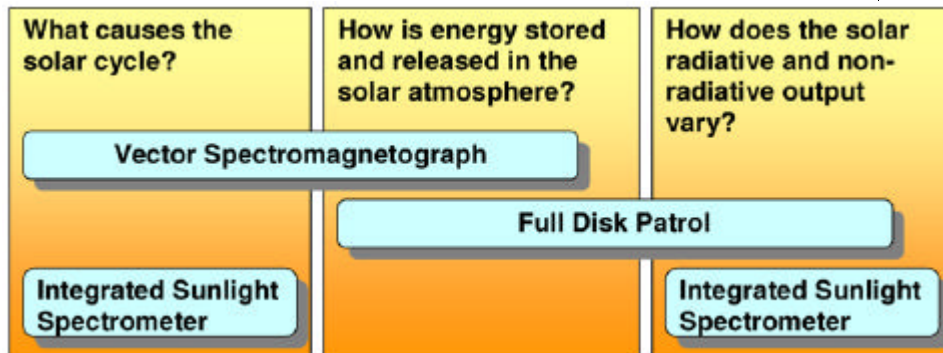
## Construction Projects

### SOLIS

Synoptic Optical Long-term Investigations of the Sun (SOLIS) is a project to make optical measurements of processes on the Sun whose study requires well-calibrated, sustained observations over a long time period. The major scientific result of SOLIS will be an improved understanding of how and why stars like the Sun produce activity, and how changes in activity levels affect the environment of the Earth. SOLIS will work in concert with other observational projects, both in space and on the ground. In particular, NASA's High Energy Solar Spectroscopic Imager will be launched at about the time of SOLIS first light and will rely on SOLIS measurements to identify regions for study.



The three SOLIS instruments are: 1) a vector spectromagnetograph for high-sensitivity full-disk measurements of the Sun's magnetic field; 2) a full-disk imager for high-fidelity spectral images of solar disk activity; and 3) a solar spectrometer for accurate measurements of spectral line profiles of the Sun as a star. The expected 200 Gb of raw data will be processed by state-of-the-art data handling systems, and reduced results will be promptly available over the Internet. Off-site users will be able to schedule particular observations to support their research and educational programs. SOLIS is expected to become operational in 2001 after a three year construction period.



As a central part of the Solar Magnetism Initiative (SMI), a proposed community-wide research program to study and understand the magnetic origin of solar variability, support has been requested to install two additional vector spectromagnetographs at widely different longitudes to obtain nearly continuous time coverage, an important addition that would provide crucial data for space-weather forecasting. If this proposal is successful, NSO would help build and install the additional instruments on a cost recovery basis.

## GONG

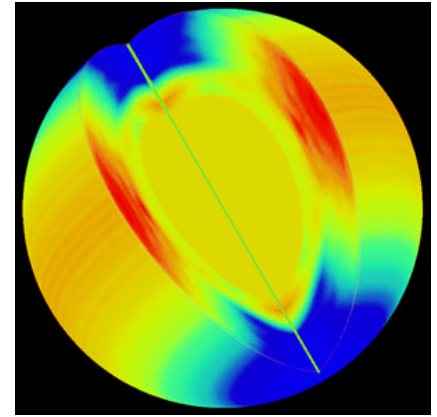
The Global Oscillation Network Group (GONG) has as its goal the study of the internal structure and dynamics of the Sun by means of helioseismology—the measurement of resonating waves that penetrate the solar interior. Results from the 6-station GONG network include: 1) demonstration that the properties of solar oscillations vary significantly over the activity cycle; 2) measurements of the variation of rotation with depth in the Sun that suggest that the source of the solar activity cycle is located in a narrow region deep within the Sun; 3) constraints on interior structure that substantially rule out the possibility that the observed solar neutrino deficit is due to inaccuracies in models of the solar interior; and 4) limits on the temporal variation of the gravitational constant that are a factor of 10 smaller than possible with pulsar timings.

**GONG+, an enhanced version of GONG, will continue to operate over a full solar cycle and will support the systematic study of variations in the structure of the solar interior with activity levels.** The enhancement involves installation of 1024x1024 cameras in place of the existing 256x256 cameras in order to enable continuous measurement of localized structures such as convection cells and hidden active regions inside the Sun (local helioseismology) and to probe closer to the visible surface.

A major data system upgrade, known as GONG++, will be required to keep pace with the higher rate of data flow and to exploit its full scientific potential. The capital cost is estimated at \$1M. In addition, we estimate that the annual operating costs will be \$0.5M higher than the amount already contained within the budget for operation of the existing GONG+ network.

## SOAR

The Southern Astrophysical Research (SOAR) telescope project has as its goal the construction of a 4.2-m telescope on Cerro Pachón. The partners in the project are NOAO, the Brazilian science funding agency (CNPq), the University of North Carolina, and Michigan State University. Thirty percent of the observing time will go to NOAO users. The telescope is being designed to achieve superb image quality (0.18 arcsec FWHM in the absence of the atmosphere), will be capable of supporting up to eight instruments at a time, and can accommodate Gemini instruments. The initial instrument complement will include a CCD imager, which will be built by CTIO, an IR imager based on HgCd arrays, a high throughput optical spectrograph, and an integral-field unit optical spectrograph. First light is scheduled for 2002.



### **Rotation Profile of the Sun**

*This image shows the internal rotation profile of the Sun as inferred from GONG data. Blue indicates slowly rotating regions while red denotes rapidly rotating regions.*

