NATIONAL OPTICAL ASTRONOMY OBSERVATORIES

FY 1989 PROVISIONAL PROGRAM PLAN

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I. INTRODUCTION

This document presents a plan for NOAO for FY 1989. To maintain all programs at the level that was set out in the FY 1988 Program Plan before the budget was reduced by nearly $3.0M would require $26.3M. In addition, NSF has indicated that GONG funding should be increased by $0.5M, bringing total required funding to $26.8M. Total FY 1989 funding requested for NOAO in the budget submitted by the President to Congress is $24.4M. Obviously, under the best of circumstances programs must be reduced by $2.4M. A broad-based review has been carried out to determine which programs are to be eliminated. This program plan is the result of that review. Specific changes that have been made to accommodate the budget shortfall are described in Section VII.

This plan represents NOAO activities for a single year. It is important to place that plan in the context of a long range plan, particularly in view of the budgetary constraints placed not only on NOAO but on ground-based astronomy supported by the NSF.

The role of the national observatories in other countries is much more clearly defined than it is in the U.S. In Europe, Canada, and Australia the national observatory operates the major facilities available to the community. Facilities in universities are limited in scope. With the full energy of an entire community focused on the national facilities, those facilities have become very powerful and dominate astrophysical research in their respective countries. The enormous increase in stature of European astronomy can in large part be traced to the development of ESO.

In the U.S. the solar facilities operated by NOAO fill a comparable role. In nighttime astronomy, however, NOAO has since its founding provided competitive but not uniquely powerful facilities. The facilities have been competitive with university-based telescopes in terms of capability and have also been perceived as competitive in less desirable ways; there has been competition, not cooperation, in developing the case for funding of astronomy, in the development of directly comparable instrumentation, and in the construction of major new facilities.

There is now an opportunity to change this situation. During the next ten years there will be an accelerated program of construction of both 4-m and 8-m telescopes in the U.S. Both NOAO and a majority of the universities interested in constructing their own facilities are prepared to explore a new way of doing astronomy--namely joint operation and construction of telescopes. The universities that have approached NOAO about such partnerships are prepared to raise the bulk of the construction costs for 4-m telescopes and some of the costs of 8-m telescopes, provide scientific input into the ongoing management of the completed facility, and build instrumentation. They look to NOAO to operate the facilities. Observing time would be made available to specific universities in proportion to their financial contribution, with the remainder going to the national community based on NOAO's fractional contribution. In this way the university-based staff can focus on the scientific program and on the development of instrumentation, while drawing on the existing expertise of NOAO to guarantee the quality of operation.

This model is somewhat similar to that adopted in high energy physics, where the national laboratory provides the accelerator and its supporting infrastructure, with university-based investigators providing instrumentation to support specific experiments.

Cooperative projects should also increase the fraction of support costs devoted to scientific activities and lower the fraction devoted to supporting the infrastructure. There are only two ways to lower infrastructure costs. One is to reduce the infrastructure to the lowest possible level, an approach adopted by Wyoming and ARC, as examples. An alternative, and one that
has the potential of producing more productive facilities overall with comparable expenditures per telescope, is to concentrate a large number of telescopes on a single site with a common infrastructure.

It is this latter possibility that many universities find attractive, and as a consequence 13 universities and other groups have approached NOAO about the possibility of joint telescope projects at the 4-m and 8-m size. It is obvious that 13 telescopes cannot and should not be built with NOAO as an active participant. Only in one case does it appear highly probable at this time that the money will actually be available, and in that case discussions have proceeded to the point of developing a draft memorandum of understanding. Presumably a few of the other proposed projects will proceed to the same degree of maturity over the next few years.

The important conclusion, however, that can be drawn from the very preliminary discussions that have occurred is that there is substantial interest in university-NOAO collaborations, with NOAO providing much of the technical skill and knowledge required to bring these projects into being and to manage a common infrastructure to support the facilities after they are completed.

This new cooperative approach may very well offer the best way of maintaining U.S. leadership in astronomy in the face of increasing investment and competition abroad. NOAO would become a primary repository of the specialized technical expertise required to instrument and operate telescopes effectively, but this expertise would be used to support not only NOAO’s telescopes but university-built telescopes as well. Each telescope built in a cooperative mode would guarantee preferred access to staff of the university that provided funding, but there would also be community access in proportion to the support by NOAO. Only needed facilities would be built; once the combination of preferred and community access meets a reasonable fraction of the need for observing time, there would no longer be a motivation for additional construction. There would be an active effort to control both costs of construction and operation, since the fraction of observing time would directly depend on costs. For universities with preferred access instrument development would become a high priority, and U.S. effort in this area would be broadly strengthened. To a large extent, NOAO’s share of operating costs for new telescopes built at either KPNO or CTIO could be provided by reprogramming of funds now used to operate smaller telescopes, and the smaller telescopes could be phased out. New telescopes, built using modern techniques and designed for remote operation, with limited instrumentation, can be operated more cheaply than existing telescopes of comparable aperture, and would in addition provide the flexibility for scheduling synoptic programs, large scale surveys, and observations requiring simultaneous measurements at several different facilities.

This program offers a way to make effective use of the total resources available to ground based astronomy, and NOAO is by virtue of its organizational structure in a position to lead the way. All that is required is a stable budget, a commitment to an effective national observatory, and a willingness to try new approaches to providing observing facilities. This joint effort would guarantee that at the end of the next decade the U.S. astronomical community would still have access to observing facilities comparable to the finest available anywhere in the world. In this same cooperative spirit, the community could then move on to conquer the next technological frontier.

The specific program outlined in this document was formulated with this long range goal in mind. For nighttime astronomy the priorities are to complete a proposal to build an 8-m telescope in each hemisphere, to begin polishing a 3.5-m borosilicate mirror as a technology demonstration project, to obtain official endorsement for a telescope project that would make use of this mirror, and to continue to develop state of the art instrumentation, particularly of
the kind that will be used with the new telescopes. Specific examples include multiple object spectroscopy, development of new CCD controllers to handle larger format arrays, achieved either with a single chip or with mosaics as technical developments dictate, and the testing and application of infrared arrays.

The role of NSO within the field of solar physics is rather different from the role played by CTIO and KPNO. While the nighttime telescopes managed by NOAO are matched by comparable facilities in universities, the small but active solar community in the U.S. is largely dependent on NSO facilities for observational solar physics. In addition to providing observing time for individual projects, NSO frequently accommodates relatively long observing runs for testing, evaluation, and application of instrumentation developed by outside groups. The use of the Lockheed adaptive optics system is one notable example. NSO also makes and archives synoptic observations of solar magnetic field structures, flares, and coronal events for use by the community. Long-term data sets spanning one or more solar cycles are crucial to many types of solar research.

NSO sees its primary mission as continuing to provide observing facilities for use by the solar physics community. Each of the facilities now in operation offers unique capabilities, and the loss of any of them would, in the view of the NSO staff, lead to the elimination of that branch of solar physics in the U.S. Continued operation of all facilities is thus the highest priority for NSO.

In addition to maintaining the core program, NSO future plans call for undertaking key projects or initiatives in specific areas of research. The major thrusts for the next five years are two: to probe the interior of the Sun through helioseismology, and to extend the capability for achieving high spatial resolution observations of the Sun over extended periods of time. Instrumentation efforts in these areas focus on the GONG project, on the development of adaptive optics, and on the continued exploration of the U.S. response to the LEST initiative to build a large Earth-based solar telescope. In addition, the application of the infrared arrays will provide an important new capability for solar physics.

NSO also intends to play a more active role in graduate education in this country. Few departments now are able to provide graduate training in solar physics. NSO has begun to explore with various universities the feasibility of establishing exchange programs that would permit NSO staff to teach solar physics at the universities and encourage students to spend time in residence either at Sacramento Peak or in Tucson.
II. RESEARCH HIGHLIGHTS FOR FY 1988

The following are representative examples of significant scientific contributions by NOAO staff and visiting scientists during FY 1988.

A. Extragalactic Astronomy.

Luminous Arcs in Galaxy Clusters.
Astrophysical processes are presumably bound by the third law of thermodynamics, and thus the appearance of very large scale, highly ordered structures is generally not expected. A surprising contradiction to this has recently been discovered by R. Lynds (KPNO) and V. Petrosian (Stanford U.). Using the KPNO 4-m telescope and a CCD detector, they have discovered extremely large, luminous arcs in two clusters of galaxies, Abell 370 and 2242-02. These filamentary objects are extremely long, about 100 Kpc, and their optical luminosity is roughly equal to that of an elliptical galaxy. Perhaps the most startling aspect of the arcs is that each one lies almost precisely along a circle whose center is coincident with either a massive cD galaxy or the center of mass of the cluster of galaxies. The color of the arcs is bluer than that of the associated galaxies. In one case clumpy structure can be seen along the arc. Originally several explanations were proposed. The morphology of the arcs is suggestive of star formation and a population of young stars, but the problem of maintaining geometric coherence over such very large scales remains. Star formation triggered by the expanding shock front associated with a gigantic explosion was a natural speculation, but it is by no means clear that this can be made to work. Other suggestions included optical synchrotron radiation, which would require an enormous amount of energy in a very special form, and gravitational lensing.

This fall Lynds was successful in obtaining spectra of one arc. Both absorption and emission lines have been identified, and the redshift is about twice that of the associated cluster of galaxies. This result has been confirmed by observations at other observatories and argues strongly that the arcs are produced by gravitational lensing.

A 100 Kpc Cloud of Ionized Gas at High Redshift: A Protogalaxy Unveiled?
With the advent of highly sophisticated CCD instrumentation, more and more information is being gathered about the formation and evolution of galaxies. In particular, it now seems clear that all galaxies did not form at a single instant, and that different galaxies evolve at different rates. The latest development in this rapidly growing subfield comes from a series of observations made by P. McCarthy, H. Spinrad, M. Strauss, W. van Bruegel (U. of California, Berkeley), together with S. Djorgovski (California Inst. of Technology), and J. Liebert (U. of Arizona). Using the KPNO 4-m telescope, the MMT, and the VLA, these investigators have discovered a large cloud of ionized hydrogen gas at a redshift of 1.82. The estimated mass of the cloud is about 100 billion solar masses, comparable to that of a normal galaxy. Deep broad band images show two faint blue objects near the periphery of the cloud, together with some faint blue regions near its center. In addition to hydrogen, spectroscopy reveals emission lines from carbon.

The nature of this object, which could not have been discovered without state-of-the-art instrumentation, remains somewhat mysterious. There is a great deal of gas, but no well defined stellar population. The blue objects are consistent with light from regions of very young star formation, and an initial interpretation of the observations is that the object is a very young galaxy or even a protogalaxy in the process of formation. There are some problems with this explanation. The presence of carbon indicates that the gas is not totally primordial, although several schemes for contaminating such gas with heavy elements have been proposed. A more significant difficulty is the presence of the strong radio source 3C 326.1 at the center of the cloud. VLA observations show this to be a "classical double" radio
source, very similar in appearance to Cygnus A. It is devoid of strong jets, bends, or asymmetric features. Such radio sources are usually argued to arise in the nuclei of old, evolved galaxies or QSOs, and hence its presence in a protogalaxy with no defined nucleus at all poses serious problems. Finally, if indeed the object is a protogalaxy, a major question needs to be answered: what caused the protogalactic cloud to "wait" until almost the present epoch before beginning its collapse to galaxy formation?

The Bootes Void: Not Completely Empty.
In 1983 a survey of galaxies by R. Kirshner, A. Oemler, P. Schechter and S. Shectman revealed preliminary evidence of a region of space in the direction of Bootes which was essentially devoid of galaxies. The existence of this giant void, encompassing over one million cubic Mpc, has since been confirmed by the same investigators. This feature has significant consequences for theories of the evolution of the universe, and it has attracted considerable attention in recent years. Further observations now suggest that the void is not completely empty, and that its inhabitants are unusual.

Using the KPNO 2.1-m and Burrell Schmidt telescopes in addition to facilities at their home institutions, J. Moody (U. of New Mexico), R. Kirshner (Ctr. for Astrophysics), G. MacAlpine (U. of Michigan), and S. Gregory (U. of New Mexico) have discovered three emission line galaxies which lie in the Bootes Void. This brings the total number of galaxies in the Void equal to ten, which is a very small number in view of the volume of space surveyed. The characteristics of these galaxies are interesting: all of them are emission line galaxies, they are small, about 10 Kpc in size, and most have irregular morphologies. All but two resemble H II regions in their spectroscopic signature. The presence of these galaxies is consistent with a void density one-tenth that of the mean, assuming the ratio of emission line galaxies to "normal" galaxies is the same here as in general. Theoretical models have been constructed which predict the existence of late forming dwarf irregular galaxies in voids with cold dark matter. However, these objects may be more luminous than can be accommodated by the current models.

Evidence for a Central Massive Component in Late Type Spiral Galaxies.
Almost all theoretical models of active galaxies employ a large amount of mass in the center of the galaxy to provide the energy required by the activity. Searches for condensed objects in the centers of nearby elliptical galaxies have been inconclusive, as have similar searches directed toward the center of our own Galaxy. Recent observations may now provide a somewhat larger scale, but well defined, limit on the central concentration of mass in some galaxies. Using the KPNO 4-m telescope and echelle spectrograph, V. Rubin and J. Graham (Carnegie Inst.) have obtained rotation curves for the nuclear regions of ten spiral galaxies.

Four galaxies in this sample are late type Sc galaxies. The somewhat unexpected result of these observations is that all four of these galaxies show rotational velocities which do not fall to zero at the center of the galaxy. Rubin and Graham show that such a rotation curve can be produced by the presence of a central mass in the nucleus, together with the usual disk and halo masses. The resolution of the telescope allows measurements to be made to within 200 pc of the centers of these galaxies, and the data indicate that about 100 million solar masses are contained within this radius. It is impossible to determine if this mass is present as a central point or as a very dense central region. The interesting result is the presence of a large amount of central condensed matter in late type spiral galaxies. These objects are not usually "active" in the same sense as Seyfert or elliptical galaxies, yet they also appear to be centrally condensed. If in fact all galaxies have central mass concentration, then a real enigma appears: what turns some galaxies "on" and not others?
Gas Dynamics in NGC 5728.
R. Schommer (Rutgers U.), N. Caldwell (CTIO/Smithsonian Astrophysical Observ.), A. Wilson (U. of Maryland), J. Baldwin (CTIO/Ohio State U.), M. Phillips (CTIO), T. Williams (Rutgers U.), and A. Turtle (U. of Sydney) completed an extensive optical and radio study of the barred Seyfert 2 galaxy NGC 5728. Broad band CCD images of this galaxy have revealed the presence of blue stars in a bright central ring which lies off-center with respect to the nucleus. Imaging Fabry-Perot observations of the Hα emission in the central regions show, in addition to a bright nucleus, a distinctive arc of ionized gas which is approximately coincident with the blue stellar ring. A radial velocity map derived from these data confirms the presence of large scale deviations from simple circular motion. In addition to S-shaped twists in the isovelocity contours at radii of 5" - 10", Schommer and collaborators detected a region of gas within 3" of the nucleus characterized by double peaked emission line profiles, with a separation of ~ 400 km/s. Long slit spectra show that the excitation of the gas in the inner regions is generally quite high, indicating that the dominant source of ionization is non-stellar radiation from the Seyfert nucleus with some local contribution due to the stars in the blue stellar ring. High resolution radio maps reveal a morphology in the central regions which is strikingly similar to that of the Hα emission.

These observations suggest that the active nature of NGC 5728 has arisen primarily from the inflow of gas into the nuclear region due to the perturbing influence of the non-axisymmetric bar potential. This model explains, at least qualitatively, the non-circular motions of the ionized gas. Gas streaming into the inner regions along straight shocks in the bar may account for the enhanced star formation observed in the central ring, or this feature may be related to an inner Lindblad resonance. Supernova remnants produced in a "starburst" may, in turn, explain the extended radio emission apparently associated with the ring. The possibility cannot be ruled out that the dynamics of the ionized gas in NGC 5728 are, at least in part, the result of the observed nuclear activity, rather than the source. This is suggested by the existence of the double emission line region near the nucleus, the jet-like extensions of radio emission, and a striking asymmetry in the ionization of the gas in the central regions.

B. Galactic Astronomy.

SN 1987A in the Large Magellanic Cloud (LMC).
A large effort was devoted by many CTIO staff members and visiting astronomers to study of the supernova in the LMC. During the first year broad band photometry and spectroscopy were obtained on most clear nights. Less frequently, infrared spectroscopy was done, and on several occasions speckle interferometric measurements were obtained by P. Nisenson, C. Papaliolios, M. Karovska, and R. Noyes (Harvard U.). Together with astrometry of pre-outburst CTIO 4-m direct plates of the supernova region and with theoretical models, a clear picture of the event emerged.

The supernova was initially underluminous but slowly rose to a maximum after 90 days in which it achieved normal brightness for a Type II event. It diminished in intensity, and beginning 120 days after outburst began an exponential decline of 0.010 mag/day, consistent with energy being produced by radioactive decay of 56Co. R. West (ESO) and collaborators showed the object to be coincident with Sk -69°202, which N. Walborn (ST ScI) et al found to be very blue and nearly superimposed in position with two other nearby hot stars. The spectrum initially showed broad H and He absorption, but quickly evolved into a complex of lines which were identified with Ba, Sr, and Sc. These elements are all produced by the s-process and must have been present in the progenitor. The IR spectrum was also rich with features in the 1 - 4 μm window, and most of these lines were identified with low excitation heavy element transitions and an emission feature of CO. The effective temperature of the outer layers of the supernova envelope rapidly declined from T_{env} = 13,000 K on the first day to 5,500 K after the first week, remaining constant there for many months. This was
The speckle images of the supernova in April 1987 produced an unexpected result: an unresolved bright source appeared near the supernova at a distance of 0.06 arcsec, corresponding to a linear distance of two light-weeks. If ejected by the outburst, the requisite velocity was $\frac{1}{2}c$. Pre-outburst images of the supernova did not show such a bright object, and any pre-existing object would have had to reconvert a substantial fraction of the luminous energy of the supernova to explain the phenomenon. Subsequent observations in June 1987 did not detect this second source, so its nature remains a mystery. It was possibly a relativistic jet accelerated by the outburst, whose brightness decreased faster than that of the supernova due to its rapid expansion. Observations of SN 1987A have continued, including high speed photometry to detect a buried pulsar in the remnant.

New Constraints on Galaxy Formation from Neutron Capture Elements.

The metal content of stars provides a wealth of information about many astrophysical processes, and often problems occur in our ability to sort this abundance of clues into a rational order. Recent observations by K. Gilroy and C. Sneden (U. of Texas), C. Pilachowski (KPNO), and J. Cowan (U. of Oklahoma), not only shed light on the abundances in metal poor Population II stars, but they also provide some important constraints on the formation of our Galaxy.

Gilroy et al used the KPNO 4-m telescope and the McDonald Observatory 2.7-m telescope to study the abundances in 20 very metal poor stars in the halo of our Galaxy. Emphasis was placed on the neutron capture elements, both rapid (r) and slow (s) process. These observers find star to star differences in these elements relative to iron, but more importantly they find r-process elements in all stars of very low iron abundance and s-process elements in higher metallicity stars. From this and the evidence that the s-process is an efficient source of element production only for stars of mass less than about 10 solar masses, it is possible to conclude that the formation of the extreme halo population of stars in our Galaxy itself formed about 16 billion years ago, occurred in a very short time, only 10 million years. This result provides a new and surprising constraint on models of galaxy formation.

IR Imaging of L1551 IRS5: Inside Collimated Outflows.

Collimated or bipolar outflows are a common phenomenon around young stellar objects and in addition to the role of magnetic fields discussed above, there is a need to discover the gas dynamics in the immediate circumstellar envelope in order to understand the outflow process itself. Insight into the nature of this envelope has been provided by using the KPNO 1.3-m telescope to provide infrared images of the source IRS5 in L1551. The observations were obtained by A. Moneti, W. Forrest, J. Pipher (U. of Rochester), and C. Woodward (U. of Wyoming).

These investigations find the object elongated, with axes of 4.1 and 2.8 arcsec. The results are consistent with a flattened circumstellar envelope 1,000 AU in diameter and viewed from about 20 degrees above its equatorial plane. The major point of interest is that the elongation is perpendicular to both the CO outflow and the optical jet associated with this object. There is in addition an ordered magnetic field parallel to the outflow. Thus the collimation and the disc geometry are probably related; whether the collimation can be achieved by the disc itself or whether the disc is a byproduct of the collimation mechanism is now the challenge that faces theoretical models.

Giants in Baade’s Window: A Clue to the Content of E and S0 Galaxies?

In order to determine the stellar content of a galaxy, it would seem necessary to first be able to see the stars. However, for most galaxies this is impossible; what is gained instead is some
spatial average of the light from all members of the stellar population within some volume. This constraint has led to long standing problems in modelling the stellar populations of galaxies, particularly in the central regions of E and S0 galaxies as well as in the bulges of spiral galaxies. A significant step towards the resolution of this problem has been made by J. Frogel (KPNO) and A. Whitford (Lick Obs.). These investigators have completed infrared observations of 185 M giant stars in Baade’s Window, using the CTIO 4-m and 1.5-m telescopes. The principal motivation is an investigation of the stellar population and evolutionary history of the galactic nuclear bulge, but these M giants also are the best sample of cool luminous stars thought to be a major constituent of other spheroidal stellar systems such as E and S0 galaxies.

The 1 - 10 \( \mu \text{m} \) observations of Frogel and Whitford show that these stars are more metal rich than their counterparts in the solar neighborhood, and that they appear to represent a population whose metallicity is significantly greater than that of the Sun. In addition, the long period variable stars in the sample show JKL colors different from all other M giants, indicating the presence of an extended circumstellar shell. These shells and the accompanying mass loss phenomena can also explain why these stars constitute most of the IRAS sources in the galactic bulge. In addition to providing insight into the bulge population, the M giants studied here have very different properties from those stars used previously to construct stellar synthesis models for other galaxies. Substitution of the properties of these stars into previously published models results in much better agreement with the observed colors of other spheroidal systems, and in particular, excellent agreement in the infrared is obtained with a measured sample of elliptical galaxies. Hence it appears that a reliable measure of the population of distant and massive E and S0 galaxies may be found in the central regions of our own Galaxy.

C. Solar System.

Molecular Emission and Dust in Comet Halley.

R. Knacke, T. Brooke (State U. of New York, Stony Brook), and R. Joyce (KPNO) performed ground-based spectroscopic observations with the CTIO 4-m telescope of the emission feature near 3.3 \( \mu \text{m} \) discovered in Comet Halley by the VEGA 1 spacecraft. At a resolution of \( \Delta \lambda / \lambda = 0.012 \) the emission consists of several components between 3.2 and 3.6 \( \mu \text{m} \) and appears to be superpositions of C-H group bands. The feature is observed out to several thousand km from the nucleus, and does not appear to be thermal radiation from the grains responsible for the 4 - 20 \( \mu \text{m} \) continuum. Molecular scattering or thermal emission by a component of cool (< 400 K) grains would require near cosmic abundance of carbon, but hotter grains would radiate efficiently enough to reduce the abundance requirement. The band shape is similar, but not identical, to interstellar absorption at 3.4 \( \mu \text{m} \), to spectra of some organic extracts from carbonaceous chondrites, and to spectra of certain synthetic molecules such as QCCs. Emission at 3.52 ± 0.02 \( \mu \text{m} \) is evidence for oxygen containing organic molecules, possibly formaldehyde or methanol.

In a program utilizing KPNO, IRTF, and CTIO facilities, linear polarization and the color of Comet Halley in broad band filters J (1.25 \( \mu \text{m} \)), H (1.65 \( \mu \text{m} \)), and K (2.2 \( \mu \text{m} \)) were measured at phase angles 9.4° < \( \beta \) < 65.3° from September 1985 to May 1986. Halley exhibited a red color characteristic of comet dust at these wavelengths with no clear variation with \( \beta \). The JHK polarizations reach 25% at the largest phase angles with a reversal at \( \beta = 20° \) and negative polarizations of a few percent at smaller \( \beta \). The polarization increases with wavelength at the larger phase angles. Previous models of the near-infrared polarization versus phase angle for Comet West fail to match the present observations. New calculations of polarization incorporating two components and power-law grain size distributions have provided better agreement.
New Concept of an Extended Solar Cycle: Solar Coronal Intensity in Fe XIV Emission Line.

R. Altrock (AFGL) has investigated the behavior of solar coronal intensity in an Fe XIV emission line observed over the last fourteen years at Sacramento Peak. His study has resulted in the confirmation of high latitude zones of solar activity. The existence of such zones has been previously suggested, but never widely accepted. The observed zones parallel the main activity zones, which progress from approximately 30 degrees latitude to the equator over the solar cycle. Localized emission peaks in Fe XIV 5303 Å are observed throughout most of the cycle at high latitudes in individual daily scans, annual averages, and solar cycle summary plots of the location of all local maxima of intensity at 0.15 solar radii above the limb. These peaks evolve slowly over a period of days, consistent with the rotation over the limb of stable features, and are similar to the lower latitude peaks that are connected with active regions. The high latitude coronal activity zones first appear at latitudes of 70 - 80°, two to three years after solar minimum. The average latitude of the zones decreases at a rate of approximately 3° per year. After their appearance, they are present more or less continuously until the following solar minimum. As they reach latitudes of 50 - 60°, these zones begin to coincide with zones in which reverse polarity (relative to the current solar cycle) ephemeral regions begin to appear, which implies a connection between the high latitude coronal activity zones and the next cycle. In addition, the high latitude zones are coincident with the fast rotating shear zones seen in rotational velocity data; this establishes a connection with regions of compressed magnetic field that have been postulated as being responsible for the formation of activity. At the current time, the high latitude coronal activity zones that appeared after the beginning of Cycle 21 have evolved into the main activity zones of Cycle 22. We thus have evidence for parallel overlapping solar cycles that begin every 11 years, but last for approximately 19 - 20 years by P. Wilson et al.

Sunspots as Sound Wave Sinks: p-Mode Wave Energy Absorbed by Sunspots.

T. Duvall (NASA), with D. Braun and B. Labonte (U. of Hawaii) are finding that sunspots absorb p-mode wave energy. The p-modes in the photosphere surrounding a sunspot were observed at the Solar Vacuum Telescope on Kitt Peak. The data are analyzed in a cylindrical coordinate system centered on the spot. In such a representation the two halves of the k - ω diagram correspond to incoming and outgoing waves with respect to the sunspot origin. They find an imbalance in the power between the two, with more power incoming than outgoing, leading to the conclusion of absorption by the spot. The absorption is a linear function of spatial wavenumber k starting near 0 at k = 0 and increasing to about 50% at k = 1.3 rad/Mm. Because each p-mode traverses a known depth range, this result may lead to knowledge of the subsurface structure of sunspots.

Chromospheric Heating in Late-Type Dwarfs: Joint Response of the Ca II K-line and Hα.

These investigations were conducted by M. Giampapa (NSO) in collaboration with L. Cram (U. of Sydney). Giampapa and Cram developed a simple model for the formation of Hα and the Ca II K-line in stellar chromospheres in order to investigate some of the properties of these features in the spectra of dM stars. The hydrogen Balmer-α line and the H and K resonance lines of ionized calcium are manifestations of magnetic-field-related, electrodynamic processes that heat the plasma that characterizes the outer atmospheres of the Sun and the late-type stars. The stellar surface magnetic fields themselves are localized in both "active complexes" (analogous to solar plages and sunspots) asymmetrically distributed on the stellar (or solar) surface, and in small "network elements" that are more uniform in their spatial distribution.

Giampapa and Cram found that the Hα line may appear either in emission or in absorption in dwarf M stars, depending on the strength of the photospheric profile, and the optical depth and electron density (i.e., the "thickness") of the chromosphere. Moreover, for a group of
stars with a given effective temperature, differences in the atmospheric heating rate in a laterally homogeneous chromosphere will create a "U-shaped" locus in the \( W_\alpha - W_K \) (H\(\alpha \) line strength vs Ca II K-line strength) diagram. The presence of lateral inhomogeneities, similar to solar plages, will move the position of a star in this diagram to points above this locus. The scatter in \( W_\alpha \) at any given value of \( W_K \) suggests the presence of lateral inhomogeneities, although stars with large values of \( W_\alpha \) (in absorption) would be expected to have relatively homogeneous chromospheres. Special astrophysical significance can be ascribed to this latter group of stars. In particular, the differences in chromospheric line strengths would reflect actual differences in the heating rate of different stellar chromospheres, independently of the existence of lateral inhomogeneities.


D. Haber (NSO) determined the equatorial solar rotation rate in the upper layers of the convection zone by inversion of five-minute oscillation data. The rotation rate appears to increase in the first two mega meters (Mm) below the surface before decreasing over the next 13 Mm. Estimates of the details of this rotational structure, however, are affected by the type of spatial filtering applied to the data. She carried out an analysis of the localized effects of a major flare on five-minute oscillations which showed slightly more power in waves travelling outward than inward towards the flaring region during the flare. The day after the flare there was substantially more power in waves travelling inward towards the sunspot region. Braun, Duvall, and LaBonte (1987) also see absorption of five-minute oscillations by sunspots, so it is likely that the 24-25 April 1984, white-light flare did locally excite five-minute acoustic oscillations.


F. Hill (NSO) has used three-dimensional Fourier transforms to analyze solar Doppler images. When displayed as slices at constant \( \omega \), or temporal frequency, the power is seen to be concentrated in rings corresponding to the familiar ridges in the two-dimensional power spectra. The shape of the rings can be approximated by an ellipse, and the ellipse parameters (position and size) are related to the horizontal velocity field and thermal structure in the convection zone. He has derived the relationship between the parameters and the flow field, and has begun fitting all of the rings available in the data. A numerical simulation shows that, (although underestimated by about 3%), the velocities can be recovered. A preliminary analysis of a small part of the data shows the presence of a substantial 100 m/s flow directed from the equator towards the south pole of the Sun. It is possible that part of the flow is caused by systematic errors such as image drift or misorientation. The ring diagrams have been obtained at four longitude bands on the Sun, allowing a search for variations in the flow field as a function of longitude. A preliminary look at a single ring obtained at the four positions suggested no variation but further analysis leaves this result uncertain.

A New Window in the Solar Spectrum: Photospheric Emission Lines at 12 \( \mu \)m.

J. Zirker (NSO), in collaboration with J. Jefferies (NOAO) and H. Jones (NASA), re-examined the formation of the photospheric emission lines at 12 \( \mu \)m, discovered by Brault in 1980. The lines have been identified as transitions between Rydberg states of neutral magnesium and aluminum. Lemke and Holweger (1987) carried out an exhaustive non-LTE study of the lines at 818.1 cm\(^{-1}\) and concluded that a small overpopulation of the upper level of the transition could account for the observed emission core and strong enhancement toward the solar limb, but were unable to explain the origin of the required overpopulation. New non-LTE calculations were made to explore the influence of several physical processes on the formation of the lines. Essentially all of the conclusions of Lemke and Holweger were confirmed. In particular, electron and neutral atom collisions are so frequent that they force the level populations to LTE, except at the very top of the photosphere, where the line
opacity is negligible. However the origin of the emission core remains a puzzle. New observations may help to solve it.

E. Interferometry and Infrared Astronomy.

Speckle Imaging of SN 1987A.
As part of the worldwide concerted effort to understand the supernova in the Large Magellanic Cloud, J. Christou (KPNO) and K. Hege (U. of Arizona) used the CTIO 4-m telescope for diffraction limited imaging of the expanding shell. They used the Steward Observatory visible speckle camera, a well calibrated and proven instrument. Since the supernova is still changing from week to week, this observation could not be exactly reproduced in the future. Therefore, to continue the results nearly simultaneous measurements were made by the Ctr. for Astrophysics team (P. Nisenson et al), using an entirely different speckle camera on another port of the 4-m telescope.

While both sets of data are still being analyzed, some preliminary results were immediately obvious. First, the supernova shell was seen to be resolved. Theoretical modelling of type II supernova lightcurves indicates that the envelope is extended and is of nearly uniform density, and that the gas does not cool significantly as it expands. After nine months of expansion at speeds up to 17,000 km/s, SN 1987A was expected to subtend a diameter of 60 to 80 milli-arcsec (mas). It is thus reassuring that the 4-m telescope, with a diffraction limited image size of 34 mas in the red, could indeed resolve the shell.

Christou and Hege also found that the size of SN 1987A's envelope is a function of the exact wavelength used to observe it. They used a technique called differential speckle interferometry (DSI) to compare the shell's extent at a particular emission feature and in the neighboring continuum of the spectrum. The on-line vs. off-line differences will indicate the physical structure of the expanding envelope.

One-dimensional data also were taken by means of speckle spectroscopy. A slit is placed in front of the speckle camera and the light is dispersed through a prism-grating combination (grism). This provides simultaneous one-dimensional scans across the object, showing how its observed size changes continuously as a function of wavelength. These observations were centered on the astrophysically important emission and absorption lines, unveiling the envelope structure and the photospheric extent over a broader wavelength range than covered by DSI.

These measurements, and additional measurements of the polarized light from the supernova, will establish whether there are any asymmetries such as might occur if there were a preferred direction of outflow. The speckle techniques, combined with the nearness of this supernova, provide details on a scale that is unprecedented.

An Infrared Revolution.
Starting on 1 September 1987, the infrared imagers for KPNO and CTIO went into regular operation for the user community. This date truly marks the beginning of a revolution in infrared astronomy, because the array imagers make it possible for the U.S. astronomy community to do observations that previously would have been impossible. Each pixel of the 58 x 62 InSb array (manufactured by SBRC) outperforms any single detector previously used for infrared astronomy. This implies immediately a dramatic performance improvement of much more than a factor of 3600.

This means, for example, that an IR map of a galaxy that previously would have taken ten hours of telescope time can now be made in 10 seconds. Stellar nurseries in our own Galaxy can now be imaged in the infrared in a fraction of a night, revealing many more young stars than had ever been seen before. In combination with other instruments, the arrays will also
provide the polarizations and infrared spectra across extended objects such as the Galactic Center or star forming regions. One of the important applications of IR imaging is for molecular clouds, where the images of H$_2$ in the infrared give much higher spatial resolution than is possible in radio observations of molecular lines.

Imaging of interacting galaxies in H$_2$ promises to provide good information on the physics of shock fronts in galaxies. The IRAS satellite discovered that interacting galaxies are among the most luminous IR objects, and ground-based IR observations have since shown that they contain an enormous amount of shocked gas. In H$_2$ emission lines alone, the peculiar galaxy NGC 6240 has a luminosity of more than 100 million suns.

Another class of objects ripe for observation is the set of bright stars now known to be surrounded by particle clouds—including α Lyrae and β Pictoris. These may be solar systems in a different state of evolution than our own. IR direct imaging and polarization imaging of these clouds are obvious next steps in understanding them.

The development and deployment of the IR arrays have resulted from the work of many NOAO staff members, among them A. Fowler, I. Gatley, F. Gillett, R. Joyce, and R. Probst. Other staff members have contributed to the special applications of the arrays, as in two-dimensional IR speckle (J. Beckers, J. Christou, R. Probst, S. Ridgway) and spectroscopy with an IR grism (J. Beckers).

**Seeing at Mauna Kea.**

Now that Mauna Kea has been chosen as a site for an 8-m NOAO telescope, we must determine how to build an observatory that will not degrade the excellent seeing there. During the NOAO site evaluation, F. Forbes and M. Merrill (ADP) found that the RMS image motion at Mauna Kea was surprisingly low, 0.2 to 0.3 arcsec at the 50th percentile. This means that the 0.25 arcsec imaging goal for an 8-m telescope is consistent with what the atmosphere can deliver.

The ultimate limit on image quality at a ground-based site is thermal turbulence within the free atmosphere. Orographic and ground induced turbulence within the boundary layer further limit image quality. But at Mauna Kea the boundary layer is very thin and its effects decrease sharply with height, most of the effect being confined to the first 10-m above the ground. Indeed, between 10-m and 100-m the thermal turbulence above the summit corresponds to a median FWHM image size of only about 0.1 arcsec.

C. Roddier (ADP), F. Roddier (ADP), and collaborators from the U. of Nice (France) and the U. of Hawaii, carried out a two week measurement campaign at Mauna Kea in 1987. They found that the free atmosphere (over 1 km above ground) contributed 0.4 arcsec (FWHM) to the average seeing in the visible. This is in good agreement with standard atmospheric models. They also found that a large part of the free atmosphere contribution came from a thin, highly turbulent layer of wind shear at a height of 5.5 km above ground.

In an experiment with exhaust fans at the Canada-France-Hawaii Telescope (CFHT), the Roddiers showed that temperature controlled air circulation might help solve the problem of thermal turbulence just above the primary mirror. While there is nothing we can do to reduce the wind shear in the free atmosphere, we can reduce the local seeing problems by controlling the ventilation, avoiding any heat sources in the building, and locating the telescope more than 10-m above ground level.
III. FY 1989 SCIENTIFIC STAFF AND SUPPORT

Scientific Staff and Support

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A. Staffing.

The quality of the scientific staff is the primary determinant of the quality of NOAO’s programs. It is the scientific staff that must bear the responsibility for identifying major opportunities in astrophysical research and for designing new facilities and instrumentation. In addition to defining the future course of NOAO, the scientific staff also plays a major role in current operations. They are closely involved with overseeing the implementation of the instrumentation program, with evaluating and maintaining the performance of existing facilities and instrumentation, and with providing the link between NOAO and the users of its observatories in order to guarantee that NOAO’s programs match the needs of the astronomical community.

Because of the importance of the scientific staff, it is essential that the program supported within NOAO offer sufficient intellectual challenge and research opportunities to allow the organization to attract and retain astronomers of the highest quality. Attention to this issue is particularly important at the present time, since NOAO has aspirations to build major new facilities for both solar and nighttime astronomy. Other universities and groups with similar aspirations are increasingly active in their attempts to recruit NOAO staff. Traditionally, NOAO has given a great deal of responsibility for instrument development and supervision of telescope performance to young astronomers, and this training has made NOAO staff attractive to other institutions interested in building and operating major facilities. Turnover of mid-career astronomers has always been high and appears likely to accelerate during the next several months.

Several concrete steps have been taken to improve the scientific environment within NOAO. Up to 25 percent of the observing time can now be assigned at the discretion of the directors of CTIO, KPNO, and NSO. Director’s discretionary time must cover all engineering and test and evaluation of instruments, but at the 25 percent level will also ensure that adequate observing time can be made available for staff research and for individuals who develop new instrumental capabilities. In practice none of the directors is using the full allocation of director’s time, but the increased flexibility given by increasing the director’s time from 15% - 25% was an important signal to the scientific staff that their research would be supported.

This past year saw restoration of the postdoctoral program, which had earlier been eliminated because of budgetary problems. The scientific staff views the postdoctoral program as being extremely important in bringing new ideas and vitality to the organization. Joining the staff at KPNO during the fall of 1987 were T. Armandroff from Yale, R. Ciardullo from Carnegie
Inst., and A. Porter from California Inst. of Technology. Joining the staff at NSO was D. Haber from U. of Colorado; D. DePoy from U. of Hawaii joined the ADP staff; and A. McWilliam from U. of Texas at Austin joined the staff at CTIO.

In the spring of FY 1988, one previously authorized postdoctoral position that had become vacant at KPNO was filled; because of the budget outlook, no expansion of the postdoctoral program was possible. Over the next several years as positions become vacant they will be reallocated so that each division within NOAO has approximately the same number of postdocs.

One of the disadvantages of being on the scientific staff at NOAO is the minimal direct support for data reduction and analysis for personal research programs. Postdocs are given the freedom to select their own research programs, and there are no graduate students or data reductions assistants. In the past the fact that the staff was responsible for every step of their scientific programs from observing to data reduction to interpretation was a serious limitation on productivity. This problem has been mitigated to a considerable degree by the availability of IRAF with its suite of powerful reduction programs designed to support NOAO instrumentation. The installation of workstations at the major telescopes on KPNO and CTIO has had the consequence that many astronomers return from observing runs with data fully reduced and ready to analyze, thus enhancing productivity.

An organization is more likely to retain staff over the long-term if it is possible for them to grow professionally by undertaking challenging new tasks. It is important to give those scientists who wish to do so the opportunity to move into leadership positions. Recent appointments to senior management have indicated that there is room for advancement within NOAO, since all have been made from within NOAO. After nationwide searches, S. Wolff was appointed Director, NOAO, and J. Leibacher was appointed Director of NSO and Associate Director of NOAO. In addition, P. Osmer was appointed Deputy Director of NOAO and D. De Young was promoted to the position of Associate Director of NOAO, with responsibility for KPNO.

All of these steps—more flexibility in the assignment of observing time, a vigorous postdoctoral program, better support for data reduction, and provision of opportunities for advancement—should serve to make NOAO more attractive to scientific staff.

It is nevertheless the case that several scientific staff are expected to leave NOAO to join other groups working on the construction of 8-m telescopes. Particularly unfortunate is the loss of J. Beckers, who is going to ESO to work on interferometric imaging for the Very Large Telescope (VLT) and the La Silla telescopes. This past year, B. Atwood moved from CTIO to Ohio State U., which is planning to build a telescope with two 8-m mirrors on a common mount; he will join J. Baldwin, who earlier moved to Ohio State U. from CTIO. J. Frogel has recently decided that he too will go to Ohio State U. Other departing staff include P. Seitzer, who left KPNO to join ST ScI, and three postdocs—P. Eisenhardt who worked in our ADP division, who has gone to NASA-Ames, E. Sadler of KPNO, who is now on the staff of the AAT, and D. Hamilton of CTIO and NOAO who is at California Inst. of Technology. The one new scientific staff appointment is J. Elias at CTIO.

The observatories within NOAO have long supported a program of postdoctoral positions. Many of the nation's most outstanding astronomers have been a part of this program. Postdocs are especially critical to CTIO; CTIO currently has two postdocs on staff. NSO has one postdoc plus a summer student program that is of equivalent cost. When NOAO can afford to do so, the Director intends to bring all divisions up to a postdoc level of three each.
B. Scientific Program.

In the text below we outline selected aspects of the NOAO science program for FY 1989. This is not comprehensive but rather provides an idea of the range spanned by our current program.


H. Abt and C. Corbally (Vatican Research Group) are obtaining UBV photometry with a CCD-direct camera of about 400 possible Trapezium systems. Such systems were identified by Poveda et al as three or more stars with separations differing by factors of less than 3.0. The goal is to obtain color magnitude diagrams, identification of members, identification as Trapezium or hierarchical systems, distances, ages, and the galactic distribution. H. Abt and D. Willmarth are obtaining improved radial velocities of 111 F8 - G1 dwarfs, using the coudé feed and spectrograph, a fiber entrance, CCD detector, and a cross-correlation against spectra of standard stars. The current accuracy is 0.6 km/s and is limited mostly by the uncertain velocities of the standards. The results to date show very few low mass spectroscopic companions.

T. Armandroff in collaboration with G. Da Costa (Yale U.) is studying the globular cluster systems of M31's dwarf elliptical companions NGC 185 and NGC 205. Spectra obtained at the Ca II IR triplet with the 4-m telescope and RC spectrograph are being used to measure radial velocities which will lead to velocity dispersions and, hence, mass-to-light ratios for these systems. Metallicities will be inferred from the strength of the Ca II lines in these spectra. CCD imaging has also been obtained at the #1-0.9-m telescope in order to perform UBVRI photometry of the clusters. Armandroff and Da Costa are also continuing their study of the Sculptor dwarf spheroidal galaxy's velocity dispersion and metallicity range using spectra obtained with the CTIO 4-m. Since their previous paper on this topic, two additional seasons of observations have allowed them to more than double their sample of member giants and to monitor the velocity stability of a subset of their sample.

D. Backman's research will concern observations and analysis of solid material around main sequence stars and theoretical studies of the relation of such material to the process of planet formation. Backman will collaborate with B. Zuckerman (U. of California, Los Angeles), I. Gatley, and R. Probst to search stellar clusters for brown dwarfs expected to be detectable in the near infrared. The NOAO IR camera will allow fairly easy detection of brown dwarfs in the six clusters younger than roughly 10^7 years and nearer than about 200 pc if interior models are correct. A null result will thus be astrophysically interesting. Preliminary studies of the Pleiades were begun with the IR camera in fall 1987. Backman will continue collaboration with Zuckerman in observations of nearby stars with far-IR excesses discovered in the IRAS data. These observations will be made with coronagraph attachments to both visual CCD and IR cameras. This is an effort to see if the far-IR excesses are caused by disks of orbiting particles. Most of the visual data has been collected at the U. of Hawaii 88-inch telescope. An attempt to study the β Pic disk with the CTIO IR camera in fall 1987 was weathered out. This would have revealed information about the scattering properties and size of the particles in this disk, vital to considerations of their evolutionary history. The proposal will be resubmitted for fall 1988. Backman will also collaborate with F. Low (U. of Arizona), F. Gillett (NASA/NOAO), and J. Lissauer (State U. of New York, Stony Brook) in an effort to model the dynamical and fragmentation history of the particle clouds studied around α Lyrae, β Pic, etc., and compare these clouds to recent models of pre-solar and pre-planetary nebulae. Backman will also collaborate with K. Hinkle and T. Hodge (Rice U.) in continuing photometric and spectroscopic studies of the 27-year eclipsing binary system β Aur, which will reach quadrature in 1989. The eclipsing body has a color temperature of 300 K and is disk shaped; its opacity and size imply that the opacity source is solid grains. Observations of the
system during the year’s approaching quadrature will take advantage of the time of most rapid change of the radial velocity difference between the secondary and primary and the fraction of the secondary observable from the Earth that is illuminated by the primary star.

M. Belton, in collaboration with H. Spinrad (U. of California, Berkeley), P. Wehinger and S. Wyckoff (Arizona State U.), and U. Pink (U. of Arizona), will continue his program to determine a precise nutational ephemeris for Halley’s comet. At present the program is in a data collecting mode having obtained a 39 night photometric time series in 1987 with KPNO and U. of Arizona telescopes and is in the process of obtaining further data with the MKO 88-inch in 1988. The goal is to combine spacecraft imaging data taken at the Vega and Giotto flybys with ground-based photometric data taken while the comet was pre-perihelion and post-perihelion to constrain a description of the complex nutational motion of the comet’s nucleus. A precise ephemeris will allow the relationship of presently unpredictable comet activity to the illumination of specific locations on the nucleus to be understood. The chief tool that will be used in the analysis is software that can analytically describe the motion that was developed by D. Borthwick (a KPNO summer student) and Belton last year. Belton will also continue his work as Team Leader of the Imaging Science experiment on the NASA Galileo project, which is due for launch in October 1989. At present the imaging teams’ work is focused on scientific software development, and in the preparation for early cruise encounters with Venus, Earth-Moon, and two asteroids. Also in the context of the Galileo effort, Belton is collaborating with D. Godfrey on a dynamical study of equatorial plume development in the atmosphere of Jupiter based on data obtained by the Voyager spacecraft. Belton also expects to complete the editing of a new book entitled "Time-Variable Phenomena in the Jovian System" which is based on the proceedings of a workshop which he helped organize in 1987 and which was held at Lowell Obs.

J. Christou. S. Ridgway and R. Probst will be working with two-dimensional infrared speckle imaging to try to push the system to its faint object limit. The recently developed 58 x 62 infrared array camera has been modified (by J. Beckers) to permit the required high magnifications. Diffraction limited mapping of infrared sources is now possible. Circumstellar shells are among the interesting topics that can be investigated by IR speckle imaging; plans are to carry out a program based on the imaging and astrophysical interpretation of these objects. In addition, IR speckle imaging will be used to search for low-mass companions of stars, and to study solar system objects such as asteroids and Io. By the end of 1988 the bulk of the reduction and analysis software for the IR two-dimensional speckle imaging should be completed.

D. Crawford has spent most of his time in the light pollution control efforts, which are proving to be quite successful. He chairs the AAS Committee on this topic, and is active in IAU work, as well as Illuminating Engineering committee work, both local and national. His scientific interests continue to be in applications of photoelectric photometry to standard photometric systems, open clusters, and galactic structure. Work in progress, much of it with outside collaborators, includes NGC 6611 and 6633, effects on systems of unresolved double stars, SA 57, and local interstellar absorption. He is also collaborating with the Automatic Photometric Telescope Service, at Fairborn Obs., in defining the telescope and photometric systems.

R. Davies is working with D. Burstein (Arizona State U.), M. Colless (U. of Durham), R. McMahon (Ctr. for Astrophysics) and G. Wegner (Dartmouth Coll.) to extend the use of the distance indicator for elliptical galaxies based on measurements of their velocity dispersions and diameters to two regions rich in galaxy clusters in the redshift range 6000 - 12000 km/s. The aim is to determine the peculiar velocities of the aggregates of galaxies with respect to each other and thus look for other examples of the "Great Attractor" phenomenon discovered by this technique beyond the Hydra-Centaurus clusters. Much of the imaging for this work is
complete; calibration photometric and spectroscopy is still required. The NESSIE fiber feed system will be used for some of the fainter spectroscopy. He is also using the infrared arrays with D. DePoy, J. Frogel and R. Peletier (U. of Gronigen) to study the stellar populations in normal galaxies. Measurements of color gradients in elliptical galaxies in J, H, and K are underway to complement the surface photometry in U, B, and R that is almost completed. In addition a sample of normal spiral galaxies has been selected for study to compare the distribution of the cool giant population with those blue stars that are the traditional delineators of structure in spirals.

D. De Young plans to continue a series of theoretical calculations which investigate several aspects of gas removal and acquisition by galaxies. Using both two- and three-dimensional hydrodynamic codes, processes such as stripping of gas by passage through an intracluster medium, infall of halo gas into the interior of galaxies, cooling flows in clusters of galaxies, supernova driven mass loss, and galactic mergers will be studied. Most of the calculations will be done using the NOAO link to the San Diego Supercomputer Center. A related problem involves the interaction of jets of gas with the interstellar medium. Controversy currently exists over the nature of this interaction, primarily because the full nonlinear calculation has not been performed in three dimensions. This problem will be studied, again using a three-dimensional numerical simulation. De Young also plans to investigate the origin of magnetic fields in clusters of galaxies. Actual detections, as opposed to upper limits, are now beginning to emerge, and a calculation will be done to examine the role of galaxy motion in providing turbulent amplification of seed magnetic fields in the intracluster medium. The calculation will treat the fully time dependent non-linear features of MHD turbulence. De Young also will continue work on a book describing the physics of extragalactic radio sources, which will be published by the University of Chicago Press.

I. Gatley and several collaborators will be concentrating on three infrared research projects. All three are made possible by the new infrared imaging arrays that are now available. First, the formation of massive stars in our Galaxy can now be studied in some detail. This is one of the subjects that cannot be investigated optically, because massive stars form in clusters inside giant molecular clouds that obscure the young clusters. Infrared observations are needed to identify sites of massive star formation, by means of their huge luminosities, typically a million times the Sun’s. With IR array cameras, we can now study the details of the stellar populations in regions such as M17, W3, NGC 7538, M42, OMC2, and DR21. Second, IR spectrometry now makes it possible to study the excitation of interstellar molecular hydrogen. The IR emission lines from hydrogen molecules contain the signature of how the molecules were excited: either collisionally in shocks or radiatively by ultraviolet light. Thus these emission lines can be used to map the physical processes within an IR source. Targets of investigation will include planetary nebulae, H II regions, Herbig-Haro objects, reflection nebulae, the galactic center, active galactic nuclei, and interacting galaxies. The third project will be a census of the stellar population of the galactic center. Gatley et al plan to map the central 5,000 square pc of the Galaxy in three near-IR bands, to determine the properties of the stars clustered about the center. Future studies of this cluster will map out the gravitational potential of the center of our Galaxy in detail.

J. Goad plans to continue her research on active and mildly active galactic nuclei. Her work will concentrate on high resolution spectroscopy, which is especially well suited to kinematic studies of the circumnuclear region. Previous and planned observations will be used to investigate the possible connection between mild activity (which is seen in some very nearby galaxies) and the Seyfert phenomenon (for which there are few nearby cases). The nearby examples of activity allow studies at high enough spatial resolution to see the immediate effects of the unknown "central engine." In recent echelle observations of ten Seyfert galaxies, Goad and J. Gallagher (Lowell Obs.) found that all but two appear to have either rapid rotation or radial flows (or both) very near the nucleus. These circumnuclear motions
may be in the same class as those being mapped by Goad, Gallagher, and M. Phillips (CTIO) in the nearby spiral NGC 253.

L. Goad will continue to devote his time in FY 1989 to adaptive optics. The major efforts are expected to be directed toward: 1) the use of artificial stars, 2) deployment of the present adaptive optics system at the KPNO 4-m telescope, and 3) development of optimal correction algorithms for adaptive optics. The use of artificial stars will be a collaborative effort with other institutions. The laser system will be developed outside NOAO, and our portion of the project will be to interface the laser system to the present adaptive optics system. The first tests of the adaptive optics system on the KPNO 4-m telescope will take place in FY 1989; system evaluation will be followed by the first attempts to obtain scientifically useful results. This will show firsthand the actual power of the device. Evaluation of the wavefront correction algorithms will be a crucial part of optimizing the entire system for use at the telescope.

R. Green is continuing his work with J. Bechtold (Mt. Wilson and Las Campanas Obs.) and D. York (U. of Chicago) on quasar absorption systems containing substantial heavy element (metal) absorption. Observations are continuing with the 4-m telescope and echelle spectrograph; previous runs have used the Intensified CCD, but upcoming runs will use the KPCA to achieve photon noise limited performance. A range of systems is being investigated, from those with damped Lyman α absorption and high column densities, allowing detection of weak tracers like Zn and C I, to those with weak C IV doublets and optically thin Lyman limits. The damped Lyman α systems may represent lines of sight similar to those passing through a galactic disk; those with strong, complex C IV absorption may correspond to regions of active star formation, perhaps in satellite dwarf galaxies; while the simple, weak systems may belong to single haloes. With 15 km/s resolution, profile fitting or accurate doublet ratios yield direct information on the physical conditions in the gas of these high redshift systems. A major long-term project was prompted by the finding of a deficit of very cool degenerates among the red proper motion stars. The consequences would be a major revision in white dwarf cooling theory, or an age of the solar neighborhood of less than eight billion years. To test this result, Green, J. Liebert and R. Wade (U. of Arizona) are analyzing a photographic color survey of some 400 square degrees at high galactic latitude, from which cool degenerates can be distinguished from halo M subdwarfs and main sequence M stars, without proper motion selection effects. Exciting additional results will be the determination of the faint end of the halo main sequence and the discovery of red extragalactic non-thermal sources. Plate scanning is now underway; the current major effort is calibration with reference to an extensive set of faint CCD standard sequences obtained for the project. Candidate lists ready in FY 1988 will lead to requests for large telescope time, to obtain spectroscopic confirmation of candidates that are optically faint and nearly featureless. The result will be a direct tracer of the early star formation history of the solar neighborhood.

K. Hinkle will continue as principal investigator for the cryogenic echelle as this instrument moves into the detailed design and early construction stage. When completed in the early 1990s, the cryogenic echelle will provide the capability for high resolution infrared spectroscopy on sources fainter than K = 10, a 100 fold improvement over the best current spectrometers. Hinkle also is continuing his research on the kinematics, atmospheric structure and abundances of long period variables (LPVs). With W. Scharlach (NRAO) a paper surveying the kinematics of 10 LPVs is being prepared. A paper on strong molecular bands in the 1.3 μm spectra of LPVs is being prepared with D. Lambert (U. of Texas) and R. Wing (Ohio State U.). Hinkle also is continuing his work on circumstellar chemistry in collaboration with J. Keady (Los Alamos Lab.). Observations are underway to search for CN created by photolysis of HCN in the circumstellar shell of IRC+10216. A long-term program of high precision radial velocity studies of K giants will be continued with D. Hall and I. Heyer (Inst. for Astronomy). Hinkle and S. Ridgway will continue their collaboration with T. Tsuji.
(Tokyo Obs.) to study the outer photospheric and inner circumstellar atmospheric regions of luminous late type stars. Hinkle will continue his collaboration with Lambert and Y. Sheffer (U. of Texas) on high mass loss, warm supergiants.

G. Jacoby will continue his study of the extragalactic distance scale using planetary nebulae as distance indicators. Thus far distances to M81, NGC 5128 (Cen A), the Leo Group (NGC 3379, 3384, and 3377), NGC 5866, and M87 have been derived. The technique relies on the universality of the planetary nebula luminosity function which is driven by the physics of the stellar evolution of the central stars. Using the maximum likelihood method to compute the shifts in the luminosity functions from galaxy to galaxy Jacoby, H. Ford (U. of Michigan), and R. Ciardullo are able to calculate distances accurate (90% confidence level) to 10% for elliptical and spiral galaxies as distant as 4 Mpc, and to 30% at distances of 12 Mpc.

R. Joyce plans to continue his investigation of the variability characteristics of very heavily obscured late-type stars, using infrared photometry and the IRAF "pdm" routine. Well determined periods have been obtained for approximately 40 M and C stars from the AFGL Infrared Sky Survey. The future emphasis of this program will be on the extremely long period (p ~ 1700 d) M stars from the AFGL, OH, and IRAS surveys which have yet to complete an observed period, and on the remaining 28 C stars from the AFGL survey which are not in the Two Micron Sky Survey (TMSS). Recent work with S. Kleinmann (U. of Massachusetts) and others on the ~ 220 C stars in the TMSS indicates that the total mass return to the galaxy is dominated by the very few extremely red objects. Infrared and OH studies of the remaining AFGL C stars will be used to derive their mass loss rates and verify that hypothesis. Infrared photometric observations of ~ 210 C stars in the antecenter direction are being analyzed to determine if the scale height of C stars differs from that of the general population or depends on the galactic radius. The KPNO Infrared Array Imager has been employed in three research programs which make use of the considerable gains in detector sensitivity and spatial resolution which accrue from the panoramic imaging capability of this instrument. The first is a polarimetric study of star forming regions associated with high velocity gas outflows. Many of these sources are characterized by a heavily obscured central source and associated infrared reflection nebulosity which is highly polarized. Polarimetry at high spatial resolution has been carried out at 1.6 and 2.2 μm on approximately 10 representative objects. The resultant polarization maps permit the discrimination between self luminous sources and those which are bright knots in the reflection nebulosity and also delineate regions of high extinction, such as dust lanes, close to the central source of directed outflow objects. A second program, in collaboration with G. Miley (ST ScI) and K. Chambers (Johns Hopkins U.), is the imaging of galaxies with ultra-steep radio spectra. A 2.2 μm image of the z = 1.13 radio galaxy 3C368, which strongly exhibits the phenomenon of alignment between the optical and radio axes, shows that the infrared morphology is also elongated and aligned along the same axis. The spectral energy distribution in the visible and near infrared is consistent with a mix of young and old stellar populations, suggesting the possibilities of a radio jet induced starburst or a primordial alignment of the radio axis with a dynamically significant population of older stars. In any case, it appears that the optical and infrared morphologies of powerful radio galaxies are dependent on redshift and/or radio luminosity. Further observations of similar objects are planned this spring using the IR imager on the 4-m telescope. An additional program in progress, in collaboration with J. Gallagher and D. Hunter (Lowell Obs.), is a survey of irregular galaxies at 1.6 and 2.2 μm. The appearance of many of these objects is dominated by the existence of OB associations and/or large dust clouds. Infrared images will be compared to existing optical CCD images to delineate concentrations of cool stars; in particular, the presence of a substantial population of red stars within the OB associations would imply an extended period of star formation. In addition, the infrared images may show underlying morphological structure not detectable in the visible due to intervening gas and dust.
E. Kibblewhite will continue to direct the design of the NOAO Interferometric Array Test Facility. Image reconstruction simulations have shown that good maps can be obtained from an array of five telescopes moving along radial tracks to a set of fixed pads. This is now the preferred design. The 0.6-m f/2 telescopes for the array have been designed. The mounts will be alt-az and the struts will be made of graphite epoxy to allow passive thermal compensation to control the distance between primary and secondary mirrors. Further tests are planned on a prototype delay line and on the relay system between the telescopes and the central station. The other major development will be in the design of the correlators. A fiber-optic prototype correlator has been built and is under test. The completion goal for the five-element array is 1991, in time for the centennial of Michelson's interferometer, but new funding must be obtained outside the core NOAO program before construction can begin.

T. Kinman in collaboration with G. Rieke and M. Rieke (U. of Arizona) will continue his visual and infrared photometry of the hundred nearest RR Lyrae stars. The program (currently 75% and 25% complete in the visual and infrared respectively) aims to get improved basic photometry for these stars that are used for statistical parallax solutions for absolute magnitudes as a function of metallicity. Improved metallicity determinations (from K-line equivalent widths) will also be obtained. When the infrared calibrations are completed, the RR Lyrae variables should become more valuable distance indicators because (inter alia) uncertainties in the extinction corrections will be reduced. Kinman is also continuing his work with R. Kraft (U. of California, Santa Cruz) and N. Suntzeff (CTIO) to determine the chemical composition of halo RR Lyrae variables that he has discovered with his survey for these stars with the Lick Astrograph. He is also starting a new program (with Kraft) to isolate the horizontal branch stars that are expected to be found with these halo RR Lyrae stars. Spectra will be taken of A and F type stars that have been found by Sanduleak in the RR Lyrae survey fields. These, together with photometric data, should allow the nature of the halo horizontal branch to be examined and thus allow a comparison of the field and cluster components of the galactic halo. The horizontal branch is an important indicator of both composition and age in these old stars. Hα emission in galaxies can be used as a powerful global indicator of the presence of star formation. Kinman has conducted an extensive survey for such galaxies in the general field using objective prism plates taken with the Burrell Schmidt. A similar survey has been made by C. Moss and M. Whittle (U. of Cambridge) for galaxies in rich Abell clusters where the environment is much denser. A comparison of the frequency of global emission found on the two surveys should give information on the extent to which this emission is collisionally induced and will therefore be greater in regions of higher galaxy density. A proper comparison requires that the discovery rates of the two surveys are known. These will be determined from the measurement of sample areas of the two surveys using the Kibblewhite machine in collaboration with P. Hewitt (U. of Cambridge).

R. Lynds, in collaboration with V. Petrosian (Stanford U.), has obtained extensive spectroscopic observations of the giant luminous arcs which seem to show conclusively that the arcs are gravitational images of objects behind the clusters in which they appear. The modelling of the contributions of the cluster members to the imaging potential is continuing, but the results seem already to be compatible with the explanation. It is hoped that future models may be sufficiently refined to both closely establish some of the mass-to-luminosity ratios for a few cluster members and to provide some spatial information on the objects being imaged. Because two such striking examples of gravitational images were so easily found, it seems a likely conjecture that far less perfect examples must be plentiful, even as recorded on existing observational material. An attempt to investigate such cases will be made. Lynds is also expecting to spend an increasing amount of time on software related to the Hubble Space Telescope.

P. Massey continued his studies of hot stars in nearby galaxies. In collaboration with J. Hutchings (Dominion Astrophysical Obs.) and L. Bianchi (Osservatorio Astronomico di
Torino), he obtained low dispersion ultraviolet spectra with the IUE satellite for a Wolf-Rayet star and an early OB star in M31. These stars had previously been identified from optical work with the KPNO 4-m and the MMT. The spectra are highly unusual, in that they show little sign of the stellar wind features which dominate the UV spectra of Galactic and Magellanic Cloud early-type stars. The weak features that are seen indicate a low terminal velocity. The metallicity of M31 is as high or higher than that of the Milky Way, and thus the expectation would be that the stellar winds would be stronger, not weaker, in M31. With P. Conti (U. of Colorado) and T. Armandroff (Yale/KPNO), Massey has also completed an optical study of the emission line properties of the known Wolf-Rayet stars in Local Group galaxies. The widths of these lines are a direct measure of the stellar outflow velocity in the region where the lines are formed, and their strength is essentially a measure of the number of atoms in that ionization state. They found that the same general relation held between these two parameters for Wolf-Rayet (WR) stars in the Galaxy, M33, NGC 6822, IC1613, the LMC, and the SMC, but that the WR stars in M31 did not seem to fit in with the others. As the metallicity of M31 is the highest of these galaxies, the deviation may be related to the effect of metallicity on stellar wind properties. In addition this study confirmed some of the lower significance WR candidates previously found by Armandroff and Massey in these galaxies by narrow band interference imaging. With the proliferation of linear detectors on Cassegrain spectrographs, spectrophotometry has become a common by-product of many spectroscopic observations. The cornerstone of such studies is the system of spectrophotometric standards. However, the spacing of wavelengths at which accurate fluxes are known for these stars is too coarse to be used with CCDs, and there are not sufficient faint standards to be used with such sensitive photon counting devices such as the KPCA. Massey, along with K. Strobel (NOAO summer student from Whitman Coll.), J. Barnes (CCS), and E. Anderson (CCS), completed work on setting up new faint standards and reobserving many of the well established standards with more frequent flux points. Data have been obtained for 25 standards, 16 of which are new, and eight of which are fainter than $V = 14$.

M. Merrill plans to resume his participation in the IR research and development program. He will be working on ways of getting the most out of IR array detectors, concentrating especially on optimizing the hardware and developing efficient strategies for data acquisition and analysis. He will also work with L. Goad on the IR application of adaptive optics. Merrill will also be working on followup observations of IRAS sources, along with F. Gillett (NASA/NOAO), and D. Backman, I. Gatley, R. Joyce, and R. Probst. This work will focus on an understanding of circumstellar environments. Targets to be observed with the IR camera and spectrograph include luminous cool stars undergoing extreme mass loss, and stars embedded in dust. On the theoretical front, Merrill will be modelling the radiative transfer in extended envelopes of stars with extreme mass loss. This will provide a critical comparison of the dust composition and various possible mechanisms for grain formation and mass loss. More realistic modelling will now be possible, as a result of the better imaging provided by IR arrays and IR speckle observations.

P. Osmer, in collaboration with S. Warren and P. Hewett (Inst. of Astronomy, Cambridge), will continue the survey for very high redshift quasars. The survey is based on multi-color plates taken with the UK Schmidt telescope. Its aims are to 1) increase the number of known quasars with $z > 4$; 2) and do so in an objective and quantitative manner, so that their space density can be determined; 3) make improved estimates of the space density of quasars for $2 < z < 4$ with the same technique; and 4) investigate the nature of quasar evolution for $2 < z < 4.5$. To date, their program has already yielded three quasars with $z > 4$, including one at $z = 4.43$, the largest redshift known. Currently, they are working on evaluating the selection effects in the survey. Osmer and Hewett are finishing their survey based on visual and APM scans of deep IIIa-J plates taken with the CTIO 4-m grism. Slit spectroscopy of the candidates has yielded a sample of 127 uniformly selected quasars with confirmed redshifts. The sample is being investigated for the clustering properties of quasars.
with $z \sim 2$. It will also provide independent information on the space density of faint quasars over the interval $1.5 < z < 3$. Osmer and A. Porter (KPNO) are studying the spectroscopic properties of high redshift quasars. There are over 50 quasars known with $z > 3$, which means that a large enough sample can be assembled to see if there is evidence for reddening at the highest redshifts or for changes in the strength, width, or excitation of the spectral lines in the $1200 - 2000 \ \text{Å}$ interval, compared to quasars at $z \sim 2$. Heisler and Ostriker have worked out detailed estimates of how intergalactic reddening could produce the observed decrease in space density of high redshift quasars; their estimates provide a quantitative framework within which the data can be compared.

C. Pilachowski will continue her study of the role of mixing to alter the abundances of carbon, nitrogen, and oxygen at the surfaces of giant stars. The observational program will concentrate in two areas, the determination of oxygen abundances in globular cluster stars, and the measurement of carbon isotope ratios in a variety of field stars, including subdwarfs. Globular cluster giants will be observed with the 4-m echelle spectrograph and CCD detector, and may benefit from the use of multi-fiber spectroscopy. A recent result of this program is the discovery of an anti-correlation in the abundance of oxygen and nitrogen in M92 giants and possible evidence for the operation of the ON-cycle in stars at the tip of the giant branch. Work will also continue with C. Sneden (U. of Texas) on the determination of carbon isotope ratios in halo stars, both to understand the effects of mixing during stellar evolution in low mass stars, and to determine the abundance of 13-carbon in the early galactic halo. Pilachowski will continue a program with T. Duvall (NASA) at the NSO to search for global oscillations in Jupiter. Data were obtained during one night in fall 1987, but a longer series of observations is required to detect oscillations.

R. Probst will continue his systematic search for brown dwarfs in young stellar systems in collaboration with B. Zuckerman and H. Epps (U. of California, Los Angeles). They are using the KPNO Infrared Array Imager in a stellar coronagraphic mode to search the immediate environs of young nearby stars for very low luminosity companions. This program makes use of the high sensitivity and spatial resolution of the instrument, together with a judicious choice of target stars, to maximize both the chance of success and the statistical significance of null results. In a related effort, Probst is part of a team led by J. Stauffer (NASA) which is redetermining the luminosity functions of open clusters. First results, for the Pleiades, indicate a luminosity function similar to the Luyten function for the general stellar field, with a high proportion of low mass stars. This contradicts earlier results which claimed a turnover before the M dwarf regime was reached. Probst and I. Gatley, with various other collaborators, are continuing to use the IR Imager to determine the properties of star forming regions. An infrared stellar census of the optically obscured molecular cloud near M42 has uncovered a concentration of young stars aligned along the CO molecular ridge. The number magnitude distribution suggests a weighting towards lower mass stars. Followup work will include regular monitoring for variability or monotonic changes in source brightnesses.

S. Ridgway will continue his work with multi-telescope interferometry projects at NOAO and IRAM, and undertake a collaboration with a similar project at the U. of Wyoming. These projects are directed toward optical aperture synthesis with three or more movable telescopes. He will serve as chairman of a newly formed working group for optical/infrared interferometry. Ridgway will continue his collaboration with J. Christou, and R. Probst in the development of an infrared speckle camera for use in the range 1.2 to 5 μm. Ridgway and P. Wannier (California Inst. of Technology) will carry out a spectroscopic study of multiple envelopes in the circumstellar shells surrounding late type stars with mass loss.

L. Wallace has completed a study of the variability of the wavelengths of Fraunhofer lines in integrated sunlight with Y. Huang (Nanjing U., China) and W. Livingston (NSO), based on spectra obtained by Livingston. Beyond its bearing on solar physics, this is a matter of importance to planetary studies since one technique for the discovery of otherwise unknown
planets about distant stars is the detection of small Doppler shifts in the stellar radial velocities about the barycenter of the star/planet system. Wallace et al have found that direct measurements of solar wavelengths relative to terrestrial molecular oxygen lines were dominated by instrumental errors and yielded unimportant upper limits of around 60 meters per second. A less direct method of measuring solar lines which have a large susceptibility to convective blue shift relative to solar lines which are relatively insensitive to blue shift, yields for moderate strength lines, an upper limit of five meters per second over the time span 1976 - 1986. Line asymmetry measurements, which are also indicative of surface convection, show an apparent trend of seven meters per second over the span 1980 - 1986. These limits on variability may be compared to the 13 meter per second component in the Sun's radial velocity due to Jupiter, suggesting that intrinsic variability in stars of solar type would not be an obstacle to planetary detection from precision radial velocity data.

Currently, Wallace is working with R. Yelle (U. of Arizona) to implement a new approach to the calculation of the line profiles of resonantly scattered sunlight by atoms in planetary atmospheres, based on a doubling principle. The basic ideas were developed by H. van de Hulst and applied in the past to monochromatic scattering problems with a highly anisotropic kernel. The doubling equations required for the resonance scattering problem have been derived, and have been successfully applied to the approximation called "complete frequency redistribution." The next step, which will take precise account of the frequency shifts at each scattering, is in progress.


During FY 1989 R. Altrock's (AFGL) research will be concentrated in three areas. The first of these is solar cycle studies of the solar corona, using data from the Sacramento Peak Emission-Line Coronal Photometer (ELCP). He expects to continue work on the variation of activity as a function of latitude and to investigate periodicities in activity, such as the 155-day period. A second area will involve studies of coronal transients. ELCP data will be searched for transients, and correlations with chromospheric, upper corona (from space-based instruments), and possibly solar wind and geomagnetic data will be investigated. In addition, work will proceed on instrumentation projects. These include a major modification to the ELCP to construct the Photoelectric Patrol Coronagraph, which will improve temporal coverage, and design and construction of a new space-based system to observe interplanetary disturbances, called the Solar Mass Ejection Imager (SMEI). Collaborations will be initiated to test the usefulness of Fe XIV 5303 A data for modelling earth upper atmospheric density. Altrock's efforts to understand the implications of and to refine knowledge of the Extended Solar Cycle will continue.

J. Brault (NSO) will reduce the observations of the UV spectra of Mo, Fe, and Ti taken at Imperial Coll. and finish and write up the final version of the energy levels of Mo I. He will work on the transition strengths and energy levels of Mo II, using both the new UV data and older hollow cathode and ICP data. He will also analyze the weaker bands of O₂ and publish the results. Measurements of the stronger lines of He I with a hoped for accuracy of a few MHz have recently been carried out by Brault in collaboration with C. Sansonetti (National Bureau of Standards) using a source developed by Sansonetti at the Bureau; these frequencies are intended as a check on QED theory, but at the same time they will provide an independent check of the absolute accuracy attainable with the FTS. As soon as they understand any problems in this first set of data, Brault and Sansonetti hope to repeat such measurements on other noble gas spectra for use as working wavelength standards.

A. Dobson (AFGL) will continue her work with stellar synoptic data. A study of the effects of differing composition on the active emission of similar age stars will be completed. Work will continue on the comparison of solar and stellar Ca II K-line observations and the identification and separation of active and quiet components of the stellar emission.
By FY 1989 NSO should be in a position to select an adaptive mirror concept and wavefront sensor concept from among the various competing technologies. R. Dunn (NSO) will continue to work on this system as his highest priority project. Other projects include: supporting the Stokes Consortium; data processing at the Sacramento Peak Vacuum Tower Telescope; and the LEST, including its site testing telescope. He is mainly interested in problems associated with high resolution imaging of the Sun.

In FY 1989 T. Duvall's (NASA) efforts in the oscillation area will be: 1) Continuation of the work on absorption of p-modes by sunspots using the Solar Vacuum Telescope on Kitt Peak. There are a number of questions that need to be answered. Does the effect disappear for small spots? What is the dependence on geometry of the region? What is causing this effect? 2) An expedition to Antarctica to observe the p-modes in the K-line. The goals of this experiment are to observe how high in degree the modes are global, to determine if there are solar cycle variations in mode frequencies, and to study sunspots and active regions using the oscillations as tracers. 3) Development of GONG instrument and analysis software. 4) Development of an instrument, called the helioseismograph, to attach to the Solar Vacuum Telescope on Kitt Peak. This instrument will facilitate observations of high-degree solar oscillations. The main purposes are to set a baseline for measurements of solar cycle variations in mode frequencies for the SOHO spacecraft and to study surface features with oscillations. 5) The study of supergranulation via oscillations. Data from the Solar Vacuum Telescope on Kitt Peak will be used to study the subsurface structure of supergranulation.

M. Giampapa (NSO) will emphasize spectroscopic synoptic studies of late-type, main sequence and pre-main sequence stars using the McMath/CCD system. He will be enlarging upon a program of synoptic observations of Hα in normal (quiescent) M dwarf stars to investigate the occurrence of rotational modulation of active regions on their surfaces. A preliminary version of this project was initiated at the McMath during FY 1987-88. Some exciting preliminary results from the project justify a concentrated effort that includes more objects and more closely spaced observations. Giampapa therefore will start a program at the McMath (beginning in FY 1988) to obtain synoptic observations of the Hα line in selected dM and dMe stars nearly every run in which the 105 mm lens and the CCD are available. Over a long-term, cycles may be detected. The detection of the occurrence or absence of cycles in dwarf stars with thick convection zones, such as the M dwarfs, is an especially important input for dynamo theory. During FY 1989 Giampapa will also conduct further synoptic observations of selected pre-main-sequence T Tauri stars. During FY 1988 synoptic observations of the T Tauri star SU Aurigae were obtained. This star is considered a "weak-emission line" T Tauri star with relatively "quiescent" characteristics. Yet the McMath observations revealed significant Hα line profile variability on a nightly basis. This represents the first time that a T Tauri star was monitored at relatively high spectral resolution (λ/Δλ ~ 42,000) during the course of one or more of its rotational periods. The striking line profile variability includes a recurrent feature that may be periodic. If so, it is likely to be a structure, such as a large prominence, that is near the stellar surface. Continued monitoring of this and one or two other T Tauri stars will be carried out in order to investigate the nature of any short-term variability that is likely present. A key question is whether variability such as that seen in SU Aurigae is related to a wind, an accretion disk, or a phenomenon with a counterpart in solar activity, such as large loops and prominences, but at an enhanced scale.

D. Haber (NSO) will investigate the interaction of acoustic waves with solar magnetic fields both observationally and theoretically. She will also work on adapting the technique of cellular automata to determining the centroids of the ridges in k - ω diagrams. This technique should give more reliable determinations of oscillation frequencies for use in inversion theory. Haber also intends to work on making the Stable Spectrograph a viable research instrument.

J. Harvey (NSO) expects to spend most of his time on the GONG project. The main task will be to make sure that the instrument produces data of the required quality. Remaining
research time will be devoted principally to three projects. First, early in FY 1989, Harvey plans to participate in a joint Bartol/NASA/NSO expedition to the South Pole to obtain high resolution oscillation observations for as long a period as possible and with as few interruptions as weather permits. The goals of this project are to measure the lifetimes of oscillations having degrees greater than 100, to produce measurements of the structure and rotation of the upper part of the convection zone, to probe local sub-surface structure around active regions, to measure the lifetime, evolution and proper motions of supergranulation and to provide baseline observations for comparison with future results from the GONG project and the SOHO mission, should it fly. Second, for the purposes of tracking possible solar cycle changes of high degree oscillations and augmenting GONG data, a project has been proposed for FY 1989 to build a high degree helioseismometer. Third, a project to study rotation and large scale motion of the photosphere has been funded by NRL with R. Howard (NSO) as the principal investigator. As co-investigator, Harvey expects to continue to work on this project.

F. Hill (NSO) would like to start looking at some older unanalyzed data available on four-dimensional power spectra of atmospheric waves, consisting of a time series of spatial rasters of line profiles. He plans to perform a four-dimensional analysis to see if there are any signatures of atmospheric waves in the data. Hill would like to obtain a time series of velocity images in and around supergranules to search for waves trapped inside the magnetic field network. A Bessel function analysis (like that used by Duvall et al for sunspots) would be used centered on network intersection regions and on supergranules as seen in the K-line. Hill would like to make some progress on his project with J. Stenflo (Inst. Astronomie, Zurich) to compute the spherical harmonics of the magnetogram data set. There are theoretical grounds for suggesting that gravity waves can cool atmospheres. There is interest also in looking for Ayres' cool regions in the infrared and see if there are any waves present. If construction of the necessary instrumentation is approved, Hill anticipates spending part of his time working on the high-degree helioseismograph development, a proposed addition to the spectromagnetograph. He will be assisting with the design and debugging of the instrument, as well as developing efficient ring-fitting algorithms for the data reduction. There is a pervasive problem in helioseismology dealing with the estimation of parameters from multi-dimensional power spectrum structures (ridges, rings, etc.). Hill would like to look into some alternatives to the usual fitting of functions involved in the application of artificial intelligence to oscillation parameter estimation. One possibility is the use of cellular automata spatial filtering and skeletonizing methods. These are currently being applied in medical imaging and robotic vision projects.

R. Howard (NSO) plans to devote more time to the study of rotation and large scale motion of the photosphere in collaboration with J. Harvey (NSO). A large amount of magnetograph data from the Solar Vacuum Telescope at Kitt Peak will be analyzed in a search for daily large scale motions of small magnetic features. He is interested in studying differential rotation and meridional and giant cell motions. Howard has undertaken an extensive program to measure sunspots on plates in a series started in 1905 at the Kodaikanal Obs. in India. This work is being done in collaboration with K. Sivaraman (Indian Inst. Astrophys.) in Bangalore and P. Gilman (High Altitude Obs.). The digital data set that results from these measurements will be combined with a similar set made at Mount Wilson a few years ago to create the largest available set of digitized position and area data for sunspots. These data will then be analyzed for large scale motions.

The formalism developed for handling the problem of radiative transfer in inhomogeneous atmospheres will be extensively applied in the analysis of the data which E. Becklin (U. of Hawaii) and J. Jefferies (NOAO) obtained at the 1988 total eclipse of the Sun. The formalism allows many applications beyond the solar context. They anticipate an extensive program being initiated in an effort to understand quantitatively the influence of structural inhomogeneities on the radiation observed from other solar features (e.g. solar prominences) where sub-telescopic features are undoubtedly playing a part in determining the characteristics.
of the spectra. In addition they hope to obtain a start on the application of the theoretical approach in the analysis of stellar spectra. The solar 12 µm lines of Mg I pose questions whose answers can open up an extremely promising diagnostic tool for the solar atmosphere, especially in its magnetic regions. The work which has been done on these lines does not give a convincing account of their excitation; further study is essential to clarify the degree of departure from LTE which some believe to be the origin of the very sharp features found in the line cores. An alternative might be the influence of inhomogeneous structures on the line profiles. The question of accounting for the characteristics of these lines is to be examined in detail.

The advent of highly sensitive infrared array detectors provides the impetus for new initiatives in solar infrared research. The Sun's infrared radiation (beyond 1 µm) has probably received less study than any other portion of its electromagnetic spectrum longward of gamma rays. The scientific case for remediying this deficiency is strong. For example: the solar atmosphere is more transparent at 1.65 µm than at any other wavelength, offering us our most direct view of the poorly understood convective processes that underlie solar activity. Or again: because magnetic Zeeman splitting of spectral lines increases with wavelength faster than their thermal linewidths, magnetic fields can be measured more directly and accurately in the infrared than is possible at visible wavelengths. Properly exploited, this opportunity should help to resolve the decades old puzzle about the distribution of true magnetic field strength in solar plage and network elements. During FY 1988-89, infrared imagers and spectrometers for the 1 - 5 µm range will be tested at the McMath telescope and applied to research programs of both visiting and staff scientists.

In addition to continued participation in the artificial data project, H. Jones (NASA) is preparing for publication a radiative transfer analysis of the response to line-of-site velocity variations of a fourier tachometer. Although still in progress, the study will explore how differential response to small variations of velocity at various phases of a five-minute oscillation at various positions on the disk affects the separation of modes in the data reduction. In FY 1989 Jones plans to finish final software development for the spectromagnetograph and to implement its operation. In addition to the standard synoptic observations, he will use the instrument for more detailed studies of the magnetohydrodynamic structure of magnetic canopies and for support of solar activity observations from NASA flight missions. Jones also plans to participate in the development of a new instrument, the high degree helioseismometer which will make use of much of the hardware for the Spectromagnetograph. Magnetogram movies made during SMM are finally being cleaned, registered, and put on optical disk, and he plans to study these in some detail. Jones plans to continue the observational study with B. Lites (High Altitude Obs.) and D. Rees (U. of Sydney) and to participate more vigorously in observational and theoretical studies of the infrared spectrum, particularly the 12 µm emission lines.

S. Keil (AFGL) plans to participate in testing and scientific application of the adaptive mirror system being developed at Sacramento Peak. He also plans to use adaptive mirrors to study flows and waves in sunspot umbrae and penumbrae, to investigate motions in prominences and spicules using He 10830 and Hα spectra, and to continue studies of motions associated with convective overshoot and waves in the photosphere and chromosphere. In addition, Keil will work on reduction of the past 12 years of Ca II K-line data, the past three years of which is almost daily (18 - 20 measurements per month). The data will be analyzed for changes in periodicity over a solar cycle as well as for changes in total emission. Experiments for the extended HRSO mission will be developed by Keil. These include the development of an XUV imager, hopefully under Air Force support, for inclusion in the HRSO mission.

S. Koutchmy (AFGL) will continue to work on the design of the prototype of the SOHO-type mirror-coronagraph with the purpose of getting ground-based white light coronal observations.
He is also reducing high resolution flux tube measurements at different photospheric and chromospheric levels in faint plages and in polar regions.

During FY 1989 W. Livingston (NSO) plans to continue the spectrum line monitoring program both at the 13.5 μm spectrograph and at the FTS. A special fiber-optic input Ca K spectrometer has been proposed for the Tucson building which, in principle, could yield daily values of the K-index to 0.01%. If such sensitivity were realized, proxy UV irradiance changes on an hourly basis might be observed.

D. Neidig (AFGL) plans to begin several observing programs aimed at 1) correlating radiative losses in the optical continuum of flares with energy deposition by nonthermal electrons, as inferred from hard x-ray bursts, and 2) acquiring spectral diagnostics for flare heating near the temperature minimum region; these two items will require modest upgrades of already existing instrumentation and involve collaborative efforts with spacecraft experiments, and 3), clarifying the relationship between chromospheric fibril geometry, photospheric dynamics, and photospheric vector magnetic fields in flare active regions that show evidence of magnetic shear. This is a major collaborative effort between the AFGL, NOAA, and NASA, with one goal being to demonstrate new techniques for flare forecasting.

L. November (NSO) will serve as the principle investigator for the Solar Synoptic Network Birefringent Filter Development Project which will receive AFGL research money starting in October 1988. The first goal of this work is the completion of vector magnetograph capability with the Sacramento Peak Vacuum Tower Telescope. This is an ongoing project that will employ our present measurement for the Tower polarization matrix and Universally Tunable Birefringent Filter (UBF). The polarization mapper will provide concurrent orthogonal pairs of circular or linear polarization states before modification by the telescope. Measurement of the polarization in specific spectral moments in any spectral line within the tuning range of the UBF filter, 4000 - 7000 Å, gives the field strength, direction, magnetic filling factor, Doppler velocity component, line width, and local intensity. The project will test the concept for application to tunable filter polarization measurement using a stand alone computer controller that can be distributed to remote sites. This design is a possible model for a Solar Synoptic Network of observatories capable of executing monitoring and forecast programs as well as certain classes of research experiments.

November and G. Simon (AFGL) have developed an algorithm for the precise measurement of the proper motion of solar granulation from ground-based white light observations. The technique has shown that the solar granulation is carried on the surface of the Sun by large scale horizontal flows in the convection zone. This probe of the convective flows reveals the supergranulation and mesogranulation flows. The magnetic network appears where the large scale horizontal flows have zero amplitude and are convergent. The divergence of the horizontal flow gives a measure of the vertical velocities and demonstrates the long held belief that the large scale convective flows are up-moving plumes. The amplitude of the flow vorticity is comparable to the amplitude of its divergence and the vortex points have lifetimes longer than a few hours. The vorticity appears to be principally convective in origin; a clear example of a Coriolis-effect-produced vortex flow is not evident in the present data. The vorticity in the flows and the strong coupling between the flows and the magnetic structures gives a viable mechanism for energizing the field structures, by twisting, which can lead to heating of the chromosphere through micro flares. Data is being obtained at the Tower that will allow examination of the proper motions in active regions in order to understand the interaction of flows with strong magnetic field structures and sunspots. Work that addresses the problem of characterizing the convective flow dynamics and its power spectrum is in progress. This work uses a new facility at Sacramento Peak for obtaining full disk white light granulation pictures.
D. Rabin (NSO) will concentrate on bringing infrared imaging and area spectroscopy to the McMath Telescope, both for visiting investigators and staff scientists. Rabin's scientific goals for this infrared work include magnetic field maps using Fe I λ 15649 and exploration of spatial inhomogeneities in the temperature minimum region using infrared bands of the CO molecule. Rabin will also continue to study upper atmospheric structure and its relationship to the photospheric magnetic field as measured by the magnetograms at the Solar Vacuum telescope on Kitt Peak.

R. Radick (AFGL) will be concluding a 10 year study aimed at characterizing the luminosity variability of lower main sequence stars on timescales ranging from days to years (i.e., rotational, active region, and activity cycle). The HAO/Lowell Solar-Stellar Spectrophotometer instrument should become operational in mid-1988, and will be starting its first year of field operation in FY 1989. Radick is a co-investigator for that project. Radick also plans to be involved in proof-of-concept testing of the prototype K-line cluster camera at the McMath.

R. Smartt, J. Zirker, and S. Koutchmy (NSO) will continue to exploit the potential of array detectors for coronal spectroscopy. Three observing programs are planned: (1) a study of spectral line profiles in coronal holes, for the purpose of deriving limits on the solar wind velocity at low heights in the corona; (2) a search for oscillations in the active corona that might reveal the presence of hypothesized MHD waves; and (3) an attempt to detect coronal magnetic fields from the very small Zeeman splitting of coronal lines.

In collaboration with J. Jefferies (NOAO) and H. Jones (NASA), Zirker plans new, spatially resolved observations of the photospheric emission lines at 12 μm, discovered by Brault and Testerman in 1980. These lines, now identified as transitions between Rydberg states of neutral Mg and Al, have considerable potential as indicators of weak magnetic fields in the upper photosphere. Further attempts to model the formation of the lines are also planned. Zirker plans further observations of the formation of solar prominences, using time series of filtergrams and spectra. Video movies of filament development, at several wavelengths, will be made, using the Universal Birefringent Filter. If feasible, simultaneous observations at 6 cm wavelength will be made at the VLA, in collaboration with M. Kundu and E. Schmahl (U. of Maryland).

Many members of NSO will be directing their research towards the study of solar activity as we approach the sunspot maximum in 1991. In addition, NSO will be bringing new facilities on-line, initiating observing campaigns, and providing coordination for community activities in conjunction with the "Max '91" initiative.

3. Cerro Tololo Inter-American Observatory.

V. Blanco and B. Blanco are continuing a series of studies aimed at determining the nature of the galactic bulge. Recent results suggest that the galactic spheroid, which extends outward from the galactic center by many Kpc, has a central component—the galactic bulge—which contains within about 1 Kpc a mass (required to explain galactic rotation) of about $10^9$ solar masses. Features of the stellar population and ISM within the bulge can be studied with photometric and low dispersion spectroscopic surveys in the so-called bulge windows. Bulge red giants and RR Lyrae variables are being studied by the Blancos. In a set of windows at longitude 0°, the giants show that a marked mean metallicity gradient exists within the inner 1.5 Kpc of the bulge. This gradient alters systematically the spectral types of the giants in such a way that the space densities of stars selected by spectral type differ considerably from what is expected from de Vaucouleurs R^n law, which is known to apply approximately in the outer spheroid. At a given galactic latitude on the 0° longitude meridian, both the red giants and the RR Lyrae stars show appreciable spreads in metallicity. These may provide clues about the evolution of the bulge.
In collaboration with M. McCarthy (Vatican Obs.), V. Blanco is surveying a number of dark interstellar clouds along the galactic equator for extremely young objects, which often show the near-infrared Ca II triplet in such strong emission that it can be easily detected in surveys with Schmidt telescopes.

D. DePoy will be collaborating with Gatley (KPNO) on the IR project to determine the initial mass function (i.e., the mix of stellar masses) in several galactic star-forming regions. Early results from the Orion Nebula and M17 suggest that these two complexes have significantly different initial mass functions. In Orion the young stellar population is similar to that inferred for the solar neighborhood, while in M17 there is a distinct lack of stars of spectral type later than about A. Understanding the causes of the observed difference is fundamental to understanding the star formation process. DePoy is also observing the infrared morphologies of spiral galaxies. Preliminary results on six galaxies indicate that many classic "grand-design" spirals have bar-like structures in the 2 μm IR light distributions. In some cases the bar is unobserved in visible light, perhaps because the optical light is dominated by too young a population of stars. The "hidden bar" may excite the density waves that make the spiral design so grand in these galaxies. DePoy transferred to CTIO from ADP in September 1988.

O. Eggen will continue his investigation of the populations of open clusters and field stars. His primary efforts will concentrate on understanding the nature of the blue stragglers. He will obtain photometry of selected clusters having a range of ages in order to determine the color magnitude diagrams, which will then be compared with theoretical evolutionary isochrones to see if the blue stragglers can be explained in terms of multiple epochs of star formation.

J. Elias and J. Frogel (KPNO) are continuing a study of infrared-bright stars in the Magellanic Clouds. The Infrared Astronomical Satellite (IRAS) database is being used to select candidate objects for observation with the 1.5-m and 4-m telescopes to make identifications and extend the IRAS observations into the near-infrared and visible. They have found that the stellar IRAS sources are mainly M type stars with thick dust shells, in both the Small and Large Magellanic Clouds, presumably counterparts to Galactic OH/IR stars. There are smaller numbers of emission line stars and carbon stars. The IRAS sources include two evolved supergiants in the LMC, which are the most luminous evolved stars in that galaxy. One of the IRAS sources in the direction of the SMC has been shown to be a luminous Seyfert 2 galaxy. The principal goal of the program is to compare the properties of OH/IR stars in the Galaxy with those of similar objects in the Magellanic Clouds. Most of their differences should ultimately be due to the differing metal abundances in these galaxies, which should affect photosphere temperatures, mass loss rates, and dust shell optical depths. During this next year, work will concentrate on an extension of the study of evolved stars to fainter limiting fluxes in the IRAS data. This requires both reprocessing of the IRAS data (by now largely complete) and further observations on the 4-m with the IR photometer and IR imager. This work is especially important for the SMC, where the present sample is too small for statistical analysis.

J. Elias is also studying low mass star formation in nearby dark clouds. Most nearby dark clouds are accessible from the Southern hemisphere, and the new IR imager is a powerful tool for surveying these clouds for low luminosity infrared sources. It should now be possible to detect brown dwarfs having sub-stellar masses during the early stages of gravitational collapse.

D. Geisler is continuing his program to determine abundances for intermediate-to-old age star clusters in the Large Magellanic Cloud. The long range goal is to derive accurate abundances for a large sample of clusters using the new technique of Washington CCD photometry. The chemical composition is a key parameter essential to determining the distance to the LMC--a topic of recent controversy. Data have so far been obtained for about 15 clusters, some in
collaboration with M. Mateo (Mt. Wilson and Las Campanas Obs.). Results are available for two clusters: NGC 2213 is found to have a mean abundance of [M/H] = -0.40 ± 0.15 and NGC 2162 has [M/H] = -0.59 ± 0.15. Combined with published main sequence photometry, the derived abundances indicate a true LMC distance modulus of 18.2 ± 0.2, confirming the "short" distance suggested by many recent CCD color magnitude diagram studies. The field giants near both clusters are found to have a mean metallicity that is very similar to that of the cluster giants. A similar program for several clusters and fields in the Small Magellanic Cloud has begun in collaboration with H. Smith (Michigan State U.). Mean abundances and their distribution will be obtained using Washington CCD photometry for about 50 clusters and 25 field giants in each of the regions of NGC 411, Kron 3, and NGC 121. These abundances are steps toward the establishment of a definitive age metallicity relation for the SMC and its distance.

Geisler, together with J. Forte (Inst. de Astronomia y Fisica del Espacia, Argentina) is investigating the extensive globular cluster system of NGC 1399, the central elliptical galaxy in the Fornax cluster. NGC 1399 provides one of the nearest and largest globular cluster systems. Washington-integrated photometry of this system, obtained recently with the 4-m PFCCD, will yield abundances for a very large sample (~ 400) of globular clusters, enabling a detailed investigation of the abundance distribution. An accurate, independent distance will also be determined from a deep luminosity function. A similar project will be carried out for globular clusters in the peculiar galaxy NGC 5128 (Cen A), in collaboration with J. Hesser (Dominion Astrophysical Obs.), H. Harris (Naval Obs.), and G. Harris (U. of Waterloo). Washington CCD images of about 25 fields around NGC 5128 should contain about 40 confirmed globular clusters with a range of properties and about 60 new clusters. In addition to obtaining metallicities, angular sizes will be estimated for these clusters.

During FY 1989, T. Ingerson will continue to devote his efforts to instrumentation, primarily in two directions: optimizing the design and performance of instruments fed by optical fibers, and in providing efficient communication between instruments, telescopes, and observers. In the field of optical fibers, a multi-object spectrograph (Argus) is being constructed at Cerro Tololo. Argus will position multiple fibers at the prime focus of the 4-m telescope, through which light will be conducted to a bench mounted spectrograph in a remote location. By the end of FY 1988 the instrument should be operational, and FY 1989 will be devoted to making it efficient, stable, and reliable to use by an unsophisticated observer. A pressing question which results from the use of a bench mounted spectrograph is how to offer the most scientifically useful set of configurations without in effect building a new instrument for every observer. This means identifying the kind of problems which are best addressed by a fiber-fed multi-object spectrograph and designing reproducible configurations which are optimized for these problems.

Ingerson and T. Lutz (Washington State U.) intend to continue their work on high accuracy radial velocity measurement through fibers, with the intention of developing a technique to make such measurements with the Argus system simultaneously on many objects. In the field of communications, new high speed serial links will be designed between instruments and computers and a high bandwidth data link established between Cerro Tololo and La Serena. The integration of these links into a system should allow smooth flow of data and control from one location to the other.

A. McWilliam will pursue a program to test the mass transfer scenario purported to explain the origin of blue stragglers. If mass transfer from an evolved companion has occurred in these objects, then CNO abundance distributions characteristic of nuclear burning should be present. The mass transfer hypothesis produces enhancements of s-process elements when the mass losing companion reaches the AGB phase of evolution. The 4-m telescope was recently used to obtain spectra of blue stragglers in M67, NGC 2477, and NGC 3532. Careful analysis
will be required in order to deconvolve the effects of diffusion and non-LTE from the true abundance patterns.

A. McWilliam and R. Williams are currently planning a program to measure heavy element abundances in a number of LMC supergiants. The goal is to determine the dependence of heavy metal abundance on the iron abundance. Galactic heavy element abundances scale with Fe down to about \(-1.0\) dex, indicating a primary origin. However, it is known that the heavy elements are secondary, being produced by neutron capture onto iron nuclei. As well as being an essentially pioneering study, it is hoped that light will be shed on the heavy element distribution with iron in the Galaxy.

V. Smith (U. of Texas) and A. McWilliam will start a program at McDonald Obs. to monitor radial velocities for a number of potential mild barium stars found by McWilliam during his thesis. The object is to test the binary mass transfer origin for these stars and to see whether they are related to the more conspicuous classical barium stars, which are all thought to be binaries. In addition, it is planned to study these mild barium stars in much greater detail in order to measure the s-process to iron peak abundances with greater precision than has been done previously. This will put membership of these stars in the mild barium class on a much firmer basis.

S. Heathcote and B. Reipurth (ESO) will continue their joint study of Herbig-Haro objects and associated optical jets, which are believed to be manifestations of collimated, high velocity outflows driven by young stellar objects into their surroundings. High resolution echelle spectra, deep monochromatic images, and low dispersion spectrophotometric measurements will be obtained of several of the most prominent southern examples of these phenomena. The resulting data will be analyzed to determine the spatial variations of velocity, density, and shock strength throughout these objects. The values of these parameters and their inter-relationships impose strong observational constraints on current theoretical models of the outflow dynamics. Heathcote and Reipurth have also begun a survey of the stellar content of nearby active, star forming clouds in Ophiuchus and Circinus. Candidate proto-stellar objects have been selected on the basis of a wide range of criteria known to be indicators of extreme stellar youth, e.g., presence of H\(\alpha\) emission on deep objective prism plates, variability, association with reflection nebulosity or Herbig-Haro knots, IR emission, and x-ray brightness. Classification spectra are being obtained of all these candidates, with the goal of obtaining as deep and complete a sample of the young stellar populations of these regions as possible. For the little studied Circinus cloud, follow up studies at IR and millimeter wavelengths are planned to exploit recent advances in the instrumentation available at the observatories in Chile.

W. Weller and S. Heathcote are continuing the study of the structure and kinematics of planetary nebulae. Using the 0.9-m, a sample of resolved galactic planetaries has been imaged in the lines of various ions. Low resolution, flux calibrated spectra have been obtained using the 1.0-m and 2D-Frutti photon counting system. The spectra are being used to place the monochromatic images on an absolute flux scale. Temperature, density, and excitation distributions within each nebula are then being derived from the flux calibrated images. Long exposure images and spectra are being searched for evidence of a remnant AGB star wind. Such ‘fossil’ stellar winds beyond the main body of the nebula are predicted by current formation theories, and evidence for their presence has been found in some nebulae. For a sample of the nebulae chosen on the basis of apparent bi-polar morphology, long slit echelle spectra have been obtained using the 4-m. The derived velocity fields are being interpreted within the framework of the interacting wind model of planetary nebula formation. The results of this part of the study will lead to an understanding of the mechanisms responsible for producing the diverse morphologies of the planetary nebulae, and insight into the nature of their progenitors. The narrow band images accumulated during this program are also being
contributed toward an atlas of Southern hemisphere PN being prepared in a collaborative effort with J. Lutz (Washington State U.) and B. Balick (U. of Washington).

S. Heathcote, W. Weller and V. Niemela (Inst. de Astronomia y Física del Espacio, Argentina), are investigating the nebula around the WN+O binary Sk - 71°34 in the LMC. During the course of a radial velocity study of the binary, this nebula was found to show extended, narrow emission lines of He II. This fact implies that the Wolf Rayet star must emit a much harder UV spectrum than is traditionally expected from stars of this type. Spectrophotometry and photometrically calibrated narrow band images of the nebula are being used to study physical conditions in the nebula, and in particular to derive the H I, He I and He II Zanstra temperatures of the exciting star. Recent models of stellar evolution including mass loss, predict that the most massive stars do, indeed, pass through a prolonged phase of very high effective temperature during core helium burning. The observations of Sk - 71°34 may therefore serve to confirm such theoretical expectations.

M. Phillips plans to continue his work on active galactic nuclei, concentrating in two major areas of study--optical variability and circumnuclear ionized gas. Over the past ten years or so, it has become clear that many Seyfert 1 galaxy nuclei show rapid variations in their broad emission lines, apparently in response to changes in the optical non-stellar continuum flux. Given sufficient data on the continuum light curve and the corresponding variations of the broad emission line profiles, it is in principle possible to determine the velocity field of the broad line region from light travel time effects within it. Also from the light curve and timescales of each outburst, one can begin to derive information on the nature of the outburst mechanism. With D. Alloin and D. Pelat (Obs. de Meudon) and A. Phillips (U. of Washington), Phillips recently obtained weekly spectrophotometric and broad band imaging observations of three Seyfert 1 galaxies--Akn 120, NGC 1566, and Fariall 9--for a six month period. These data, which are currently being analyzed, represent the most intensive coverage to date of active galactic nuclei variability. Similar observing campaigns are planned for the future. At the same time, Phillips and collaborators have continued to build up a database of spectroscopic observations for several Seyfert galaxies which, although less frequently sampled, covers a period of many years. With these data, it should be possible to examine longer timescale phenomenon which, again, should help to provide further insight concerning the mechanism of nuclear variability.

In collaboration with R. Schommer and T. Williams (Rutgers U.), Phillips plans to obtain imaging Fabry-Perot observations of the ionized gas in a number of nearby Seyfert galaxies as part of a more general program to study the circumnuclear environment of such objects. One of the main purposes of the Fabry-Perot observations is to critically examine the evidence for inflowing gas near the active nucleus, thereby providing a test of the idea that nuclear activity is fed by gas from the main galaxy disk, channeled into the central regions due to the effects of a non-axisymmetric potential (e.g., a bar or a nearby companion). With such data, it will also be possible to look for evidence of the disruption of disk gas by past explosive events. Phillips and collaborators have already published Fabry-Perot observations for one object--the barred Seyfert 2 galaxy, NGC 5728--and have recently obtained data for several other barred galaxies with active nuclei. These observations will be combined with optical and infrared images, as well as radio maps, of the same objects to produce a more complete picture of the relation of the circumnuclear environment to nuclear activity.

M. Phillips, S. Heathcote, N. Suntzeff, and J. Elias will continue to carry out a program of frequent optical and infrared observations of bright supernovae. From the accurate light curves and spectra obtained, several aspects of supernova research are to be pursued. These include:

(a) SN 1987A--The brightest supernova to appear in 383 years has provided a unique opportunity to study the nature of type II supernovae. Although its early evolution was
somewhat unusual (due largely to the fact that the progenitor, Sk -69°202 was a blue supergiant), SN 1987A is now behaving as a normal type II event. It should be possible to follow the optical and infrared spectral evolution for several years, during which time the products of explosive nucleosynthesis will be fully revealed. Eventually, it may also be possible to observe the neutron star thought to have been formed in the explosion as a rapidly rotating pulsar.

(b) The Nature of Type Ib Supernovae—Some massive stars apparently end their lives, not as type II supernovae (like SN 1987A), but in an explosion more closely resembling a type I event. The nature of these supernovae, which have been dubbed "type Ib", is currently the subject of considerable interest. It is particularly essential that an accurate picture of the optical and infrared spectral evolution of such objects be obtained. Phillips and collaborators hope to provide such data by following several type Ib events over the next few years.

(c) Type Ia Supernovae as Distance Indicators—Because of their great luminosity, supernovae have attracted considerable interest over the years as potential distance indicators. Of the different classes of supernovae, the classical type I events (now referred to as "type Ia") appear to hold the most promise as standard candles. The optical light curves of type Ia supernovae show a dispersion in maximum luminosity of ~ 0.5 magnitudes. In the infrared, the agreement is even better (~ 0.2 magnitudes). However, recent observations of the type Ia supernova 1986G in Centaurus A by Phillips and collaborators have shown that small differences do, in fact, exist between at least some type Ia events. It is important, therefore, that future type Ia supernovae be observed to the same precision as SN 1986G so that such differences can be more accurately quantified.

N. Suntzeff with E. Olszewski (U. of Arizona), R. Schommer (Rutgers U.), and H. Harris (Naval Obs.) are studying the overall kinematics of the Large Magellanic Cloud. A new catalog of stellar clusters in the LMC compiled by Olszewski and Schommer in the halo regions not covered by the previous surveys has allowed us to probe the outer regions of the LMC and thus its full gravitational potential field. Individual M and C giants in these clusters are to be observed at the 4-m RC/Air Schmidt spectrograph. Single 3-min exposures lead to 2 km/s accuracy which will greatly improve the previous analysis of the stellar kinematics pursued by Freedman, Illingworth, and Oemler (FIO). About one half of the clusters have been observed to date, and already our results are showing great differences with the FIO work. We have not seen the large kinematic differences between the young and old cluster populations as suspected in FIO. This study should provide the best analysis of the total internal kinematics of the LMC.

In a similar study, Suntzeff and E. Hardy (U. of Laval) are studying the overall kinematics of the SMC based on field carbon stars identified by M. Azzopardi (Marseilles) and V. Blanco in two separate studies. The idea has been advanced that based on the kinematics measured from H I data, the SMC is actually two galaxies superimposed on the sky. About half the sample of carbon stars has been observed at 1.5 km/s accuracy, and it is becoming clear that the stellar velocities are different from the H I data. The double peaked nature of the H I data is just not seen in the stellar population.

D. Terndrup is continuing a multi-year program of studying M giants in the galactic nuclear bulge with Blanco, Frogel, and Whitford. Optical spectroscopy and near-infrared photometry will be carried out on several hundred M giants at galactic latitudes between -3° and -12°. Although detailed analysis of the data is just beginning, two results stand out. The first is that all of the M giant studies differ noticeably from their solar neighborhood counterparts usually used in the models. The strengths of TiO bands in the 0.7 to 0.9 μm region are considerably stronger at constant color in the bulge stars. Also, the JHK colors of the bulge stars differ systematically from those determined for solar neighborhood stars, presumably because of some as yet unidentified blanketing effect. The luminosities of the bulge stars are
up to two magnitudes fainter at constant spectral type than those of stars used in models. Second, there is now convincing evidence for radial gradients in most of these observed parameters. As one looks further away from the center, differences between bulge and solar neighborhood M giants decrease systematically. New information about the structure of the inner Galaxy will result from the above survey and from a re-analysis of CCD photometry in the bulge. All indicators of the density of the bulge--RR Lyraes, K and M giants, IRAS stars, and the integrated light of the entire population--have a steep decline with radius, at least as fast as the $-3.5$ power of radius. A new survey of the bulge parallel to the disk, begun last year by Blanco and Terndrup, will provide important information on the structure of the inner bulge, thereby extending our knowledge of the structure of the Galaxy to the inner two Kpc. Also, Terndrup is completing a several year program to provide new, faint UBVRI standards in the range $16 < V < 19$. The new standards are an extension of the widely used Graham E-region standards, but are much better suited for CCD observations on large telescopes.

R. Williams will continue to study the structure of accretion disks in close binary systems. High spectral resolution time resolved spectra of emission lines will be obtained of eclipsing cataclysmic variables during primary minimum with the 4-m telescope. As the secondary star cuts across the disk, occulting various sections with their different velocities, substantial changes in the line profiles occur over a period of minutes, and these can be used to map the emission geometry of the disk. Initial data from two objects have yielded results that indicate that some novae and nova-like systems may not possess accretion disks, since the expected blue-to-red line variations do not occur during eclipse. A realistic representation of the emission requires stream velocities perpendicular rather than parallel to the binary orbital plane. Also, Williams, H. Ford (ST ScI), G. Jacoby and R. Ciardullo (KPNO) are systematically taking deep Hα CCD frames of NGC 5128 in order to discover novae in the Galaxy. In three years, 12 novae have been discovered. The spatial distribution, rate, and luminosity of novae in the system will be determined, with one of the results being their calibration for use as standard candles. A preliminary result is that the nova rate per unit light is two to five times lower in the elliptical component of Cen A than in the bulge of M31.

The abundance of s-process elements in stars in the LMC will be studied by Williams and A. McWilliam. One of the results of the spectroscopy of supernova SN 1987A was the enhancement of barium and strontium in the envelope. The ratio of Sr/Ba, presumably produced in the progenitor, appears to be different from prediction by evolutionary models of massive stars. Therefore, another source of s-process elements may have enriched stars in the LMC. Normal late-type supergiants in the LMC will be observed with the 4-m echelle, and the absorption profiles analyzed with the aid of a model atmosphere program in order to derive the distribution of s-process elements in the stars. The objective is to identify the relative importance of the different sources of the s- and r-processes in determining the heavy element abundances in the Large Cloud.

A. Walker will continue his study of the distance scale calibration by determining mean magnitudes for RR Lyrae variables in the Large Magellanic Cloud, concentrating on variables near the cluster NGC 2257. Comparisons between the Cepheid, Mira, and RR Lyrae distance scales will be possible, and measurement of field RR Lyraes, including some that possibly have higher metal abundance than the cluster stars, will test the magnitude-metallicity relation. In addition, a search will be made for Cepheid variables in the important radio galaxy, NGC 5128 (Centaurus A), in order to provide an accurate distance to the galaxy. The data will also be useful for a study of the luminous stellar content of NGC 5128. Walker plans to complete his measurements of the light curves of the many RR Lyrae variables in the galactic globular cluster IC 4499, to allow a detailed comparison with the theory of the horizontal branch, and will continue to collaborate with V. Castellani (Rome) in the analysis of photometry of stars in the young LMC cluster NGC 1866, for comparison with evolutionary theory.
IV. MAJOR PROJECTS

A. GONG.

The Global Oscillation Network Group (GONG) is an international project to conduct a detailed study of the internal structure and dynamics of the closest star by measuring resonating waves that penetrate throughout the solar interior—helioseismology. To overcome the limitations of current observations imposed by the day-night cycle at a single observatory, GONG is developing a six-station network of extremely sensitive and stable solar velocity mappers located around the Earth to obtain nearly continuous observations of the “five-minute” pressure oscillations. To accomplish its objectives, GONG is also establishing a major, distributed data reduction and analysis system to facilitate a coordinated analysis of these data. The primary analysis will be carried out by a dozen or so scientific teams, each focusing on a few specific categories of problems. Membership in these teams is open to all qualified researchers.

The project got underway officially in FY 1987, and by the end of FY 1988 it will have begun the integration of the various components into a complete full scale prototype of the field observing instrument station. This automated instrument features a doppler analyzer based upon a Michelson interferometer coupled to a lightfeed, camera, and data acquisition and computer control system. The site survey network will continue to acquire data on the observing conditions at the various potential sites. The development of the data reduction and analysis system continues with the addition of two more programmers assigned to work on the data reduction pipeline and user analysis interface. The science teams from the solar physics community have been formed and continue to provide input to a wide range of project requirements in the areas of data reduction and analysis, as well as the development of solar models, and the comparison of various inversion techniques. The project continues to hold its annual meeting and to sponsor various topical meetings and workshops.

The originally requested FY 1988 budget of $2.5M was cut by $1.5M to $1.0M. This precluded the purchase of any of the components for the six field stations themselves. Since capital outlays from the budgets of two consecutive fully funded years are required to build the stations, these cuts have delayed the beginning of the observations by at least one year.

A funding level of $2.6M was initially proposed for FY 1989, in order to return the project to its original funding profile. This would have held the completion delay to one year and avoided further delays. However, NSF has reduced this FY 1989 funding request to $1.5M. Thus, over the first three years the project will have received less than one-half of the funding proposed in the original project plan. As a direct consequence, the beginning of observations will be delayed yet another year. Network science operations cannot be anticipated before October 1992, two years later than the target date.

It should be pointed out that the above scenario represents an optimistic picture in which $1.5M is actually received in FY 1989 and the project returns to the original funding profile, corrected for inflation, in FY 1990 and subsequent years. Such a view would require the following long-term funding:

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This will lead to a total runout cost of some $17.7M. The two-year delay in completion, including the inflation on delayed funds, has raised the total cost of the project by $2.7M over the $15.0M required by the original funding curve.
GONG Milestones

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<tr>
<td>April 1989</td>
<td>System design review</td>
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<tr>
<td>April 1991</td>
<td>Begin integration of field station components</td>
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<tr>
<td>October 1991</td>
<td>Computing system hardware ordered</td>
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<tr>
<td>April 1992</td>
<td>Begin network installation</td>
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<tr>
<td>October 1992</td>
<td>Network operations begin</td>
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<tr>
<td>October 1995</td>
<td>Network operations cease</td>
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<td>October 1996</td>
<td>Initial data reduction complete</td>
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At the current funding level the prototype field system will be completed, debugged, and operated to validate the overall design and to develop specifications for the acquisition of the six field systems. In addition, a limited amount of long lead-time and other high priority components of the field systems will be put out for bid and purchase. These items will include certain specialized optical and machined components and those more common components which are required early in the construction process.

The development of the data reduction and analysis system will continue with attention to the database management, pipeline reduction, data archiving, and analysis problems. A variety of hardware issues, including main processing machines, high density archiving systems, and distributed processing equipment, will continue to be studied. This development will be supported by the addition of two more programmers and a Sun file server system. The Sun system will be a prototype of the final GONG storage and archiving system and will include a combination of magnetic and optical disks, as well as high density rotary head cassette tapes.

The site survey will continue and focus increasing attention on support/logistical aspects, as well as the strictly observational attributes of the various candidate sites. The project will continue to support a wide range of contributions from the science teams through both individual interactions and group activities, such as team workshops and the annual GONG meeting.

B. Future Telescope Technology.

Throughout 1987 the development of large mirrors continued to be the major part of the Future Telescope Technology (FTT) work at NOAO. Much of this work remains directly applicable to NOAO plans despite a major policy change in August of 1987. At a meeting in Keystone, Colorado, representatives of the AURA Board and AURA's Future Directions Committee recommended that NOAO propose to build 8-m telescopes instead of the National New Technology Telescope at this time. Long range plans suggest a start on the 16-m NNTT in the mid-1990s.

In a statement issued in September 1987, the AURA Executive Committee said that "This program is a key step toward the development of 16-m and larger telescopes." In this document "AURA asks the NOAO to develop the detailed scientific justification and technical specifications for the [8-m] telescopes, and to work with AURA to prepare a detailed implementation plan and proposal." Accordingly, NOAO has begun a series of working meetings to prepare such a proposal.

Many members of the NOAO staff have contributed to a detailed draft of the research projects that could be done with 8-m telescopes in the Northern and Southern hemispheres. Several small working groups (comprising experts both inside and outside NOAO) are discussing plans for a first complement of instruments. Some of the ideas for the NNTT instruments can be carried over to the 8-m planning. NOAO has been working in collaboration with the
Magellan Project staff to consider concepts for the optical support structure and the alt-az mount. In addition to fork mounts, a new "rocking chair" concept is under analysis, making use of two large wheels on the altitude bearings. Various concepts for an 8-m telescope enclosure are also being considered with an eye toward minimizing artificial air-turbulence.

Mauna Kea, Hawaii, is the site chosen for NOAO's Northern hemisphere 8-m telescope. The seeing and infrared characteristics of this site are known to be superb (NNTT Technology Development Report No. 10, March 1987). In November 1987, F. and C. Roddier organized a two-week campaign of measurements at Mauna Kea to get a better understanding of the origin of the seeing. Results of this study will be used to determine the exact location and height of the 8-m telescope and to design an effective enclosure. In the meantime, some of the site testing equipment has been sent to CTIO for an evaluation of possible sites for a Southern hemisphere 8-m telescope.

The AURA work on large primary mirror development has three parts: (a) The U. of Arizona Mirror Lab. is building the furnace and turntable needed to spin-cast large honeycomb blanks from borosilicate glass. This work is funded through AURA Contract No. 2788032 (R. Angel, Principal Investigator). Detailed plans for the mirror casting project are available separately and are updated as part of the annual contract renewal process. (b) At NOAO the FTT engineering group has an ongoing program to design, test, and control large honeycomb mirrors. Until September 1987 this program concentrated on experiments with a 1.8-m prototype honeycomb mirror cast at the Mirror Lab. Preparations are now underway for tests of a 3.5-m honeycomb mirror scheduled for casting in 1988. (c) Together with Corning the FTT group is developing the concept of liquid cooled ULE and fused silica meniscus mirrors. Liquid cooling of these mirrors allows the elimination of mirror seeing and the testing of their optical surfaces at field temperatures. They offer an alternative to the borosilicate glass mirrors.

The highlight of the year at the Mirror Lab. was the first test casting made with the large new spinning furnace. This was a 48-inch honeycomb blank to be used by the Smithsonian Astrophysical Obs. on Mt. Hopkins. When it was removed from the furnace in December 1987, both core geometry and bubble content were seen to be better than for any of the previous castings. This successful casting proved out most of the hardware and procedures to be used for the first 3.5-m casting in the spring of 1988. The first successful 3.5-m blank will be used by the Astrophysical Research Consortium (ARC) for their Apache Point Telescope. The second 3.5-m casting, scheduled for late 1988, will be polished at NOAO and then thoroughly evaluated.

The mirror evaluation work at NOAO during FY 1989 will consist of several parts:

(1) Implementing new mirror polishing and rapid optical testing methods using the upgraded 4-m polishing/testing facility and borosilicate glass mirrors.

(2) Designing and testing supports for lightweight structured mirrors that can be used under active control to partially compensate reflecting surface errors. This will be implemented next for the 3.5-m blank and will be extended naturally to the 8-m size.

(3) Developing effective ways to monitor and control the temperatures in and around structured mirrors. Previous tests on the 1.8-m borosilicate glass mirror show that thermal control will be necessary if 0.25 arcsec imaging is to be achieved.

(4) Assisting as appropriate in the application of FTT Program technology to other telescope projects.
Exploring alternative mirror options such as Corning’s liquid-cooled ULE meniscus mirrors, described in a paper delivered at the ESO Conference on "Very Large Telescopes and Their Instrumentation," March 1988.

Modification of the 4-m polishing machine at NOAO is nearly complete. The new lap will be motorized instead of free-wheeling, to enable greater control over the polishing of aspheric mirrors. After a first test on the existing 1.8-m f/2.7 mirror, the machine will be used to polish an f/1.75 paraboloid on the second 3.5-m honeycomb blank. The automated CCD Hartmann system, used so successfully for optical tests of the 1.8-m mirror, will be applied to the 3.5-m testing as well. Rapid and highly accurate testing is one of the keys to the production of large mirrors capable of producing 0.25 arcsec images.

Before the 1.8-m prototype mirror tests were completed in September 1987, two different modes of active control were tested. In the "open-loop" mode, the force actuators received instructions based only on thermal distortions indicated by the 237 thermistors in the mirror. In the "closed-loop" mode, the corrective forces were calculated from real time measurements of the optical surface itself. Both modes significantly improved the mirror’s surface (by a factor of just over 1.5). In preparation for the delivery of a 3.5-m blank, we have done finite element analyses to evaluate active optical control of this size mirror. The next step will be to assemble the optical surface information in order to find the optimum force combination. Design of an active support system for an 8-m honeycomb mirror will require new computational techniques since this size mirror will have about 1,540 pockets, five times as many as are in a 3.5-m mirror.

For thermal monitoring, the 237 sensor system will remain in the 1.8-m mirror while it is being re-polished at NOAO. At the same time, a "1000-sensor" system is being designed for a 3.5-m mirror. The next step toward thermal control of a 3.5-m mirror will be a series of tests on a "mockup" consisting of one-sixth of a 3.5-m honeycomb. This will be a three-way collaboration among NOAO (who will provide the thermal sensing system), ARC (who will build the forced air ventilation system at Apache Point on Sacramento Peak), and the Carnegie Institution (who will provide the mirror segment mockup). The goal is to evaluate a thermal control system on a real telescope. We hope to have the experiment set up on the ARC telescope in the fall of 1988.

This experiment is consistent with NOAO's goal of making the new telescope technology available to other projects as well as the NOAO 8-m telescopes. Thermal control will, of course, be vital to the success of the 8-m telescopes. The liquid cooled ULE meniscus mirrors offer another possible means of thermal control, with a liquid flowing through channels built into the mirror blank. The options will be detailed in an 8-m telescope proposal, which we plan to complete near the end of 1988.

C.  WIN.

4-m Telescope Projects. In the proposal to the NSF to renew its contract for operating NOAO for the next five years, AURA described the need for additional 4-m class telescopes and defined an approach for meeting this need without using NSF support for construction.

The most pressing scientific requirement is for a telescope optimized for high and moderate resolution multiple object spectroscopy. Such a capability would have obvious applications to the study of the evolution of clusters of galaxies; for the determination of the cosmological constant \( q \); for studies of the large scale structure of the universe; for analyses of the evolution of stars in clusters and of stellar populations.
Since that proposal was written, NOAO has had serious discussions with three university consortia interested in undertaking the construction and operation of 4-m telescopes at NOAO sites and in partnership with NOAO. Two groups are interested in placing telescopes in Chile. The third proposal is to place a 3.5-m telescope at Kitt Peak. That project will require action during the next year, and so is described in some detail here.

Specifically, the project at Kitt Peak would be carried out by a consortium consisting of Wisconsin, Indiana, and NOAO. The telescope would make use of a 3.5-m mirror scheduled to be delivered to NOAO in early 1989 by the Steward Observatory Mirror Laboratory. The mirror would be polished and mirror support and thermal control would be developed by NOAO as part of a technical demonstration project for spin-cast honeycomb borosilicate mirrors. Wisconsin and Indiana would provide funds to construct a completed telescope. The design would follow very closely the design of the ARC telescope on Sacramento Peak to minimize cost, construction time, and technological risk. Wisconsin and Indiana are the only universities who have been willing to meet NOAO’s constraints on this project—use of an f/1.75 borosilicate mirror, conditions required by the technology development program; location on Kitt Peak, to facilitate performance tests and minimize operating costs; and optimization for multiple object spectroscopy.

NOAO’s responsibility would be to provide a completed mirror and to operate the telescope at a defined cost level for a fixed period of time, currently set at 15 years, on behalf of all of the members of the consortium. Observing time would be divided according to financial contributions of the three partners, but the goal is to have the financial contributions be such as to correspond to 50% observing time for NOAO, 30% for Wisconsin, and 20% for Indiana.

NOAO proposes to finance its share of the operating costs, estimated at $300,000 per year in FY 1988 dollars, by closing enough small telescopes (probably two) to free the necessary operating money. The WIN telescope would be placed at the site of the #1-0.9-m telescope, and that telescope will be closed during the summer of 1989. The capability for CCD imaging now provided by the #1-0.9-m telescope would be moved to the #2-0.9-m telescope.

NOAO’s share of the observing time would be reserved for large scale surveys, synoptic programs, and observations that must be made simultaneously with measurements at other wavelengths, and in particular by HST. The telescope would be operated by NOAO staff, with remote observing an option as technology makes that possibility attractive economically. The WIN telescope would therefore make it possible for the NOAO community of observers to carry out programs that are not now feasible with existing instruments.

Initially, the telescope would be designed to be used in the optical and near infrared only. Instruments would be permanently mounted in order to minimize operating costs. One Nasmyth focus would be made available to Wisconsin and Indiana for university developed instrumentation; NOAO would not be responsible for maintenance of this instrumentation but would maintain the facility-class instrumentation, including the multiple object spectrograph. NOAO will also be responsible for building the multiple object spectrograph. If funding permits, a duplicate of the instrument now under construction for the 4-m Mayall telescope would be built. If funding does not permit, then the instrument would be moved from the Mayall to the WIN telescope.

In addition to providing a qualitatively new kind of scientific capability, the WIN project would set the precedent that NOAO can participate in consortia and would establish the mechanism and ground rules for doing so. It is likely that a similar consortium can be established for at least one of the proposed 8-m telescopes. Building the WIN would provide valuable experience that will be useful in building the 8-m telescopes. The responsibility for the continued quality of performance and operation of the WIN would be assigned to NOAO,
which has experience in this type of activity. Wisconsin and Indiana do not wish to undertake the burden of operating a telescope. The use of an existing site and infrastructure will minimize long-term operating costs.

A draft agreement is being developed by Wisconsin, Indiana, and NOAO and will be presented for review to AURA and NSF during the next 12 months.
V. INSTRUMENTATION

This chapter describes the instrumentation program that is planned for the next year. In order to define this program, each of the four divisions within NOAO was asked to prepare written proposals describing the projects, both new and continuing, that they wished to pursue. Input from the Users' Committees was an important part of the planning process. The divisions then prioritized the proposals, indicating what they would do if funding were level with respect to FY 1988 and what they would do if modest increments of funding were available.

These proposals were then reviewed by the Instrumentation and Program Advisory Committee (IPAC), which was chaired by P. Osmer and included one representative from each division as well as three outside members—S. Keil, G. Rieke, and L. Robinson. IPAC met in open session in Tucson and reviewed all projects in terms of scientific impact and technical feasibility. In executive session, IPAC prepared a report for presentation to the Associate Directors of NOAO. In most cases, all three levels of review—divisional, IPAC, and the NOAO Associate Directors—were in agreement about program priorities.

In addition to specific priorities, IPAC expressed very strongly its concern about funding for instrumentation. It is their view, which is shared by NOAO management, that the available resources, especially for non-payroll items, are far below what is essential for a national observatory program. For example, NOAO is not now able to place new orders for infrared and optical array detectors. The cost of one infrared or large CCD array is close to the total non-payroll amount of the NOAO infrared, KPNO optical/ultraviolet, or the CTIO instrumentation budget and therefore is beyond the range of what can be considered this year. The funding level for NSO projects is perhaps even tighter. In these circumstances, no division in NOAO is in a position to complete major new projects in less than three to four years. As a consequence, no major new instrumentation will be placed in service in the next few years.

The funding is most acutely inadequate in the non-payroll area, but the committee did not recommend reducing manpower in order to supply the necessary capital for equipment purchases. The committee felt that, given the high-tech nature of current instrumentation, the present staff was needed to test, install, and maintain equipment even if it was purchased outside. In addition existing equipment must be kept operational. In its report, the committee stressed that it felt that the requirement was for increased capital resources for NOAO to carry out its mission.

The committee also called attention to several projects authorized in earlier years and already in progress that will require significant resources and higher rates of expenditure in future years in order to be brought to successful completion. These are, in no special order, 1) the adaptive optics at ADP and NSO; 2) the distributed array project in ADP, for which a separate proposal to the NSF will eventually be prepared; 3) the cryogenic echelle (where a desirable array is likely to be costly); 4) large format optical detectors (we will surely need more large CCDs than have been ordered); 5) computer workstations (IPAC can see the need for 13 - 14 additional units in NOAO). Because of budget limitations the distributed array project has been discontinued; and computer workstations have been deferred.

The following paragraphs describe the specific program in more detail.
A. Kitt Peak National Observatory.

Summary of KPNO Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Payroll</th>
<th>Non Payroll</th>
<th>Total</th>
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<tbody>
<tr>
<td>IR Detector Research and Development</td>
<td>225K</td>
<td>27K</td>
<td>252K</td>
</tr>
<tr>
<td>Cryogenic Optical Bench</td>
<td>90K</td>
<td>29K</td>
<td>119K</td>
</tr>
<tr>
<td>Cryogenic Echelle</td>
<td>225K</td>
<td>57K</td>
<td>282K</td>
</tr>
<tr>
<td>2D Speckle Upgrade</td>
<td>12K</td>
<td>10K</td>
<td>22K</td>
</tr>
<tr>
<td>IR O&amp;M</td>
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<td>131K</td>
</tr>
<tr>
<td>GaAs Intensifier for Adaptive Optics System</td>
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<td>20K</td>
<td>27K</td>
</tr>
<tr>
<td>Artificial Guide Star Tests</td>
<td>63K</td>
<td>15K</td>
<td>78K</td>
</tr>
<tr>
<td>IR Array Camera</td>
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<td>45K</td>
<td>90K</td>
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<tr>
<td></td>
<td>728K</td>
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KPNO O/UV

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<th>Payroll</th>
<th>Non Payroll</th>
<th>Total</th>
</tr>
</thead>
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<td>KPAC Time Mode</td>
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<td>32K</td>
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<tr>
<td>TV Acquisition Cameras</td>
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<td>315K</td>
<td>82K</td>
<td>397K</td>
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</table>

The infrared program, although it is budgeted under Kitt Peak, serves all of the divisions of NOAO, and activities throughout the observatories are coordinated through monthly teleconferences of the IR Steering Committee. In addition to the infrared programs described here and scheduled to be carried out in Tucson, CTIO proposes to develop a digital signal processor that is fast enough to accommodate the output of larger format arrays, the high data rates encountered at longer wavelengths, and the high speed requirements of the interferometric applications. CTIO also wishes to build an additional infrared photometer.

IR Detector Research and Development. The implementation of array detectors in imaging cameras for the 1 - 5 μm region at KPNO and CTIO has placed NOAO firmly at the forefront of infrared astronomy. NOAO achieved early success in this area because of its deep involvement in development of the SBRC 58 x 62 InSb array for astronomy. Now that the challenging task of fabricating the imagers is nearly complete, it is necessary to return to a vigorous program of R&D in detector evaluation.

Already, there has been a successful test of a Si:In 58 x 62 array. The Si:In array is important because larger array formats may be relatively straightforward with Si technology, while problems are anticipated in building larger format devices analogous to our InSb array because of thermal stresses between dissimilar materials. We have also recently obtained a contract to evaluate 10 μm Impurity Band Conduction (IBC) detectors; IBC detectors are similar to those previously described in positive terms by Houck and Herter. Other detectors are awaiting tests. Identification of the detector for the Cryogenic Echelle is a crucial task for the R&D effort. We plan to begin definition and scientific justification for a 256 x 256 array development proposal. A major limitation of the testing program is the fact that there is only one lab dewar for all evaluation and engineering tasks including telescope tests, closed
cycle cooler evaluation, etc. This project would correct that deficiency and provide support for the testing program.

Cryogenic Optical Bench. The project to build a cryogenic optical bench was described in the program plan for FY 1988. The Cryogenic Optical Bench is a flexible, versatile second generation infrared imager. Its intent is to greatly expand the capabilities of infrared imaging by installation of a variety of modular spatial and spectral filters between telescope and detector in an "optical bench" format. These modules can be used singly or in serial combination, and can be reconfigured on line while observing. This makes for an instrument of great power which will dramatically increase the scientific output of infrared arrays.

Specific capabilities include:

1. Narrow band filters with approximately a 1% bandwidth centered on spectral features may also serve as order sorters for Fabry-Perots. One application is to imaging of planetary nebulae, for which early results show differences in the distribution of ionized versus molecular gas; these differences are diagnostic of both physical conditions in the nebulae and, from generic morphology, the status of the precursor star.

2. An infrared grism which images entire atmospheric windows (e.g. the 2.0 - 2.4 K band) across the array at 1.8% resolution can take over the role of single element CVF spectroscopy with both simultaneous wavelength measurement and long slit capability.

3. A stellar coronagraph has been used with the existing imager to search for brown dwarfs and to image the disk around β Pictoris. These experiments with warm elements demonstrate the need for a cold focal plane to obtain optimum results.

4. A Fabry-Perot interferometer is a convenient way to provide greater spectral resolution than is achievable with filters and offers both velocity resolution and continuum suppression. This technique has been applied at UKIRT to the galactic center in order to trace the velocity field of the central molecular ring. A major advantage of imaging H₂ in the infrared is that much higher spatial resolution can be achieved than is possible in radio molecular line observations.

5. Polarimetry of dusty sources can be used to identify the illuminating source, develop shell models, and detect elongated disks, which constrain mass loss in many objects ranging from young stellar objects to planetary nebulae.

6. The linear analog of a CVF serves the same functions as fixed filters but with continuously variable wavelength. For simple line imaging, linear variable filters (LVF) allow work in numerous lines across a spectral window for which an equivalent set of fixed filters would be cumbersome and expensive to provide--especially for redshifted extragalactic targets. One program that becomes feasible with these filters is the study of the spectral evolution of galaxies with lookback time.

Fixed filters, K band variable filters (LVFs), and polarimeter components have already been purchased, ADP has provided a grism, and coronagraph optics have been supplied by B. Zuckerman and H. Epps (U. of California, Los Angeles). Several of these components have already been used successfully with the existing imagers at CTIO and KPNO. A conceptual design for the optical bench itself is approaching completion, and mechanical fabrication should be completed in FY 1989. With completion of the cryogenic optical bench, two imagers will be available on Kitt Peak for use by NSO programs as well as for nighttime astronomy.
Cryogenic Echelle. Both the cryogenic echelle and the scientific justification for it were discussed extensively in the FY 1988 program plan. High resolution infrared spectroscopy will be possible on entire classes of infrared objects in our Galaxy as well as a large number of individual stars in globular clusters, and even in M31. In addition it will be possible to observe a large number of galaxies and globular clusters in integrated light. The spectrograph will be at least a factor of 100 times faster than the best current high resolution infrared spectrographs (e.g. the 4-m FTS).

After exhaustive review involving major community participation (the scientific justification is now 56 pages long), it was decided to build a fixed resolution $R = 100,000$ instrument with a velocity baseline of at least 1000 km/s—the simplest, and so the most cost effective design available. This decision removes any necessity of opening the instrument on a regular basis, and so dismisses some concerns about logistical and scheduling issues. It also clearly identifies a major direction for detector R&D, for at least 256 pixels in the dispersion direction are very desirable. The design will be completed during FY 1988 and construction will begin in FY 1989.

2D Speckle Upgrade. Infrared speckle interferometry (IRSI) is a powerful tool for the study of sources which are infrared bright, and frequently optically invisible; which are expected to show structure on angular scales between the seeing limit and the diffraction limit of large telescopes; and for which the flux and morphology as functions of wavelength provide basic data directly and/or constrain models in useful ways.

The simplest structure after a single unresolved source is a pair of unresolved sources, i.e. a binary system, with arbitrary separation and flux ratio. Speckle imaging of binaries therefore provides a valuable test of hardware, software, and of speckle techniques. Binaries are also of intrinsic interest, primarily as fundamental calibrators of the stellar mass luminosity law. IRSI can be used to obtain direct individual mass determinations for low mass binary components and to search for substellar objects as binary companions. Together with other search techniques for very low mass companions it can provide observational data for comparison with models of star and planet formation. Recent results from hydrodynamic codes suggest that star-star versus star-planet systems result from quite distinct processes, and there is not a continuum of secondary masses from stellar to jovian mass. Recent stellar evolutionary models also indicate that the commonly used empirical mass luminosity law may be seriously in error at very low (stellar) masses. This would have a significant impact on estimates of the mass density contributed by these high M/L stars. Both of these theoretical results can be tested directly by means of IRSI.

IRSI of embedded sources in molecular clouds will be very useful for the study of early stages of stellar evolution. The angular diameters of blackbodies brighter than $m (4.8 \mu m) = +1.5$ are greater than 0.05 arcsec for temperatures of about 500 K, a common color temperature for compact sources. Radiative transfer calculations predict strong variations of diameter with wavelength which are susceptible to direct test. One may also see source asymmetries related to the dynamics of star formation, which would go unnoticed photometrically. A serious limitation of one-dimensional slit scanning speckle methods has been incompleteness of position angle coverage, with resulting uncertainties in interpretation.

At the other end of the stellar life cycle, it is possible to study mass loss from late-type giants. Much can be deduced about the shell structure, temperature, grain size, and radial intensity distribution.

A developmental IRSI system employing the KPNO IR Array Imager, operated through a DEC 11/73 computer, warm re-imaging foreoptics, and a high speed warm shutter has been used successfully at the 4-m telescope. Despite the presence of warm elements in the beam, the
data remain strongly read noise limited at speckle frame rates. Thus until arrays with significantly lower read noise become available, this simple combination of hardware is state of the art and is fully competitive with dedicated instruments being proposed or under construction elsewhere.

Funding in FY 1989 will permit addition of a storage device that can handle the large speckle data volume conveniently.

**IR O&M.** The infrared group is responsible for upgrades to existing IR instrumentation and for all but routine maintenance. Accordingly, funds are assigned to the instrumentation group for this activity.

**Image Intensifier for Adaptive Optics.** An adaptive optics system has been constructed and is ready for initial tests at the McMath. The system is likely to be tried at the KPNO 4-m telescope during FY 1989. The sensitivity of the adaptive optics system is limited by the gain of the current image intensifier. The Reticon readout noise is larger than the photon noise of the input signal after intensification. This project would provide an additional GaAs intensifier to increase the system gain ahead of the Reticon detector, and also to improve the red sensitivity of the system.

In the absence of the detector upgrade, we estimate that the useful sensitivity limit of the adaptive optics system will be approximately 7th magnitude. Within this limiting magnitude, it will be possible to evaluate the system and obtain astronomically useful observations of regions surrounding the brightest stars. The inclusion of the requested image intensifier will extend the system magnitude limit to roughly 12th magnitude, at which point the system becomes a practical astronomical tool and may be used for studies at high angular resolution of planetary nebulae, nova shells, and other phenomena involving stellar outflows.

**Artificial Guide Star Tests.** At present, the adaptive optics system is limited in its usefulness to regions where there is a bright reference star within the isoplanatic patch of the region being imaged. By using an outgoing laser beam to project an artificial star, we have the possibility of creating a bright reference object for wavefront sensing at any desired location in the sky. Furthermore, the star so created may be bright enough to permit correction of visual, as well as infrared images.

Several research groups are now developing suitable laser systems for use in the production of artificial guide stars. The most promising prospect appears to be the use of a laser at the Na D wavelength for excitation of the resonant scattering in the Na layer 90 km above the ground. This project would support the modifications necessary for the attachment of such a laser to our adaptive optics system for evaluation of the laser guide star technique. The laser system would be supplied by one of several possible collaborators. The NOAO effort would consist primarily of integration of the optical system and modifications to the wavefront sensor.

**IR Array Camera.** A near infrared array based camera is needed for use as a speckle camera, in adaptive optics imaging, and as an infrared wavefront sensor. The large and increasing number of requests to use the single KPNO InSb imager already make it unrealistic to expect that these needs can be met without the construction of another camera. The capital funds provided here represent about half the cost of an infrared array detector; the remaining capital costs will be supplied by NSO, which also wishes to have access to an IR camera, and manpower will come from the NOAO IR group.

**Fiber Actuators.** Many spectroscopic programs will benefit from the multi-object capability provided by optical fibers. Areas of research that will take particular advantage of fiber
spectroscopy include studies of the evolution of clusters of galaxies and their dynamical
 evolution, star formation and chemical enrichment histories of member galaxies, and
development of the hot intracluster medium; studies of physical processes in such objects as
planetary nebulae, supernova remnants, and H II regions through mapping of temperatures,
densities, velocity fields, and abundances; the study of knots, condensations, and filaments in
supernova remnants; the study of flows of protostellar material in the regions surrounding
young stellar objects; spectroscopy of stars in clusters to study patterns of element
enrichment, activity, mixing, and mass loss. A detailed discussion of the scientific
justification for multi-object spectroscopy was presented in the program plan for FY 1988.

Kitt Peak has chosen the 4-m RC focus as the location at which to provide a multi-fiber
capability. The RC focus offers a 40 arcmin field of view with negligible distortions, easier
access, and a plate scale that permits the use of 200 - 300 μm fibers, which are easier to
handle than the smaller fibers that are required for work at prime focus.

The approach to making the fiber actuators will be similar to that used with the AUTOFIB
system at the AAT. The ultimate goal is to have 50 - 100 positioners, and the use of a
magnetic system permits the installation of additional fibers on an incremental basis with
modifications to the software but without requiring construction of a new actuator for each
new fiber.

Magnets, prisms, and hypodermic tubing are being acquired to construct prototype "fiber
buttons." Various off-the-shelf high precision X-Y tables are being evaluated. The pickup
mechanism is the most complex component of the instrument, and we are exploring the
systems used by AUTOFIB and by the Lick system. The selection of commercial subsystems
will be made in FY 1988, and the fiber actuators constructed in FY 1989.

**Bench Mounted Spectrograph.** A bench mounted spectrograph will be optimized in design to
match the fiber optic characteristics. The collimator must be fast enough to collect the
outgoing spectrograph beam and central obscurations must be minimal to avoid light loss in
the central portion of the light beam. The collimator must also have a wide enough field of
view to accommodate a long entrance slit for a large number of input fibers.

Mounting the spectrograph on an optical bench rather than on the telescope will enhance
stability by eliminating flexure related problems. The spectrograph can also be housed in an
environmentally controlled room. Construction on a standard optical table will provide for
ease of construction and alignment and easy accessibility for cleaning.

In FY 1988 the schedule calls for completion of the concept design, ordering of parts and
materials, and the start of detailed design. Optical and mechanical fabrication will begin early
in FY 1989.

**KPCA Time Mode.** The study of rapidly varying phenomena and the allowance for
atmospheric seeing effects both require access to the full time resolution of the KPCA. The
KPCA is capable of producing a full frame every five ms, with even shorter times for partial
frames. This technical capability has applications to such problems as searches for optical
pulsars, for which the large sky coverage of the KPCA is an advantage; image enhancement by
rapid guiding and superposing short exposures by centroiding on a reference source; and for
speckle interferometry.

This exploratory project would modify the KPCA electronics to provide for the output of the
individual photon events, along with a frame marker, for later analysis and investigation of
algorithms. Real time processing would be implemented only after experience has been
obtained with different algorithms. Typically, a few hundred photon events per frame
corresponds to data flows of a few hundred kilobytes per second, so that, in the initial configuration as envisioned, and without buying any extra high speed storage device, which is not planned at this time, only quite short observations will be possible. Short exposures will, however, be adequate for experimental tests and for defining what will be required for a complete high resolution facility.

**TV Acquisition Cameras.** Acquisition cameras are required to support optical and IR observing in a control room environment—to identify the field of a target object, identify the target if bright enough, and guide from a star, or stars, in the observable TV field. To accomplish these primary goals it is necessary to see as faint as technologically possible. A reasonable minimum goal is to see fainter than the human eye.

Although they are much maligned, the current ISIT acquisition systems are actually very good detectors and have the ability to register each photo-event. The ISITs are, however, too large to install in some areas of interest such as the 2.1-m Gold Guider dissector housing, and so TV guiding cannot be used for most applications at this telescope. The ISITs are also limited by the quantum efficiency of the front end image tube. CCD systems offer gains of up to a factor of three in quantum efficiency, but the noise introduced with a bare CCD limits the net gain substantially unless the CCD is cooled and controlled with first rate electronics.

The goal of this project is to begin to replace the ISITs with an intensified CCD (ICCD) which yields similar quantum efficiency in a smaller, cheaper, lighter package. These systems can be built from off-the-shelf components (intensifier and CCD camera) and integrated in-house, or purchased directly as a package from a vendor. Preliminary tests of a commercial system indicate that it is possible to replace the dissector scanner used at the 2.1-m with a camera that would yield a guide limit about four magnitudes fainter than currently available, faster guide star acquisition, and no need to move the guide mirror, thereby eliminating the flooding experienced by IR imager observers from viewing the back of the guide mirror. During FY 1989 we will continue testing commercial systems and purchase an off-the-shelf system from one vendor. The commercial systems have costs comparable to an ISIT. Gains in sensitivity can also be achieved by paying proper attention to details such as pixel scale matching and by post-processing of the video signal. It is usually these factors that lead to inadequately faint acquisition with current ISITs at the 4-m and 2.1-m.

**CCD Controller.** This is the continuation of a project being led by CTIO to provide a new generation of CCD controllers characterized by stability and low noise, with the capability of handling multiple CCDs and multiple quadrant readout. The controllers will be modular to permit easy upgrading and will be interfaced to the UNIX/Sun/IRAF environment. Preliminary work has shown that much of the higher level architecture for the CCD and IR controllers can be made common.

Funds for FY 1989 will permit Kitt Peak to build a controller based on the CTIO design and to upgrade a prototype that is to be constructed in FY 1988. The two systems would be used at the 4-m and 2.1-m telescopes, and could accommodate large format Tektronix CCDs, should they become available, or multiple CCDs.

**CCD Development.** These funds provide support for characterization and optimization, chip mount design, and new dewar construction. Examples of activities supported in the past under this program include an imaging run on the Kitt Peak 2.1-m with the first Tektronix 512 x 512 thinned device seven working days after its receipt; optimizing the UV flood sensitization recipe for TI chips, starting from the Steward Observatory formula and achieving even better results in blue DQE and stability; and construction of a chip mount, dewar, and control electronics ready for receipt of 2048 x 2048 devices from Tektronix when they arrive.
Details of activities for FY 1989 will be determined as specific devices become available. We expect to receive more Texas Instruments CCDs from the NSF distribution through JPL, including mechanical samples for experiments in mounting and cooling. Kodak has a megapixel CCD with small (7 μm) pixels. JPL and Kodak are making such devices available; characterization of their performance cold under low light will be valuable both for Kodak and for us. Several devices from Tektronix remain on order; corporate management there remains committed to producing large format chips and is currently negotiating a contract to provide such chips to NASA for the Hubble Space Telescope.

Further experimentation on CCDs also proceeds under this program. It includes adjustment of clock voltages and integration phases to maximize charge transfer, minimize pixel to pixel variations, and reduce surface dark current accumulation. If the STIS program starts to provide small format Tektronix test devices, techniques of application of anti-reflection coating will be investigated, which would increase their overall DQE substantially.

**O/UV O&M.** The instrumentation group occasionally assists with maintenance and major repairs of operating CCD systems.

**B. National Solar Observatory.**

**Summary of NSO Projects**

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<thead>
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<th>NSO/Sunspot</th>
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<td>Helioseismograph</td>
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<td>Stellar K-Line Filter</td>
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<td></td>
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* NSO scientific staff R&D funds  
** NSO telescope improvement funds

**Achieving the Resolution Limit: Adaptive Optics.** High resolution studies of solar phenomena on subarcsec scale will play a vital role in advancing solar physics over the next decade. Many of the basic physical processes in the solar atmosphere occur on spatial scales below one arcsec. For example, the interaction between magnetic flux and photospheric convection, which generates most of the fine structure we observe, and which heats the overlying layers, can only be studied with solar images that attain subarcsec resolution for periods of at least several hours.
A major goal of the NSO instrumentation program is to provide improved spatial resolution for extended periods of time through the use of real time adaptive optics in conjunction with the sophisticated light analysis equipment already available at the Sacramento Peak Vacuum Tower Telescope. A prototype adaptive optics system, developed by R. Smithson (Lockheed) with support from the AFGL, has already been tested. This system incorporated an active mirror of 19 segments, each of which can be moved independently to correct local wavefront tilt while maintaining phase with its adjacent elements. The system successfully compensated image motion and improved image resolution. The goal now is to develop a second generation, user friendly adaptive optics system, specifically designed for permanent installation and regular use on site at Sacramento Peak.

The adaptive optics program can be broken into several sub-tasks. It is necessary to develop or buy a mirror with enough active elements—37—to compensate totally the full aperture of the main Vacuum Tower Telescope. These active elements must be tilted at a rate fast enough to follow changes in the incoming, distorted wavefronts from the Sun. A wavefront sensor capable of measuring the distortion of wavefronts is needed. Finally, since the real payoff comes from feeding the corrected light signal to further analyzing equipment, an optical layout for feeding spectrograph, filter systems, and other instrumentation is needed.

During FY 1989 the goal is to construct or buy an adaptive mirror, with the decision being based on tests and evaluation to be completed in FY 1988, and to construct a wavefront analyzer. Completion of this project in FY 1989 would require $414K in NSF and Air Force funds, and progress will depend on the actual level of funds and manpower available. The primary consequence of lower funding levels is delay in completion of the project with correspondingly somewhat higher total cost.

Calibrated High-speed Image Recording Processor (CHIRP). Many solar observing programs involve the acquisition of two-dimensional arrays of spectral profiles as a function of time. For example, to follow the evolution of an active region before it flares, observers typically want to record several spectral lines in two spatial dimensions to derive density, temperature, magnetic field, and Doppler velocity. With large format CCDs an enormous amount of data can be acquired in a morning. In order to calibrate the data in real time and to reduce the raw data to a small set of useful physical quantities (e.g., Doppler velocity, magnetic field), NSO has been developing the CHIRP over the past two years. It consists of a distributed processor system interconnected with a Proteon token-ring local area network. This project will permit an upgrade of the Vacuum Tower controller from a 6800 to a 68020 microprocessor, installation of a 6250 bpi tape interface, and modification of the slip ring.

High Resolution in the Corona: Mirror Coronagraph. Many subtle, but important, coronal phenomena are barely detectable with existing emission line coronagraphs. Coronal structure, is for many problems, not adequately resolved, it is difficult to make measurements beyond about 1.2 solar radii, and high quality spectra, particularly in coronal holes, are extremely difficult to record.

This project will investigate the feasibility of a new technology coronagraph based on a super-polished objective mirror, rather than the super-polished singlet lens, which has been traditionally used on coronagraphs. An off-axis configuration is required, and an objective mirror of at least 1.5-m aperture is the ultimate goal. Such a coronagraphic-type telescope has recently been proposed, independently, as a space-borne system for direct imaging of extra-solar planetary systems.

Recent tests of a super-polished (about 2 Å rms) 5-cm aperture silicon mirror on loan at Sacramento Peak confirm that this mirror has excellent scattered light properties. The goal of the project proposed here is to construct a scaled down version of a large coronagraph.
with a super-polished glass-substrate mirror objective, 20-cm aperture, f/20. In addition to being a valuable test bed, this would be a research quality instrument that could be installed at the Evans Solar Facility.

For Precision Polarimetry: Polarization Compensator. Magnetic fields influence much of the structure, dynamics, and energy transport in the solar atmosphere. The ability to measure vector magnetic fields, at spatial scales at or below an arcsec, would lead to major advances in understanding the solar cycle, the buildup and release of solar flare energy, and the formation and decay of sunspots—to name only a few topics. To obtain such measurements, NSO, in collaboration with the High Altitude Observatory, is building a Stokes Polarimeter, to be installed at the Sacramento Peak Vacuum Tower Telescope, which is the only U.S. instrument capable of subarcsec imaging. The optical train of the telescope introduces a small but significant instrumental polarization, which must be measured at all configurations of the telescope optics, and an optical compensator has been designed to cancel the instrumental effects while observations are being made. The compensator will certainly correct the observed circular polarization (for the longitudinal magnetic field) and may also be sufficiently accurate to compensate the linear polarization (for the transverse field). The observations may also be corrected by means of a post-observational calibration technique.

The compensator for the circular polarization will employ two waveplates, which will be positioned by servos controlled through the Vacuum Tower's control computer. The servo design will be based on that used in the GONG instrument for rotating the AGC polaroid.

High Energy Flare Research: Multi-band Patrol Upgrade. The Multi-band Patrol images of solar active regions are used to study white light flares, the formation, evolution and dynamics of active regions, and to provide good quality large scale images for comparison with data acquired at other telescopes.

This project is to replace the present single objective, rotating filter wheel design with a quad-type system consisting of four objectives and fixed filters operating at 3610, 4275, 4950, and 7000 Å. All four images would be formed and photographed simultaneously on a single film frame using fine grain holographic film. The new design offers the advantages of reduced film consumption and avoidance of changes in atmospheric seeing between successive exposures at different wavelengths. A design is already in hand and tests for exposure and film spectral response are in progress. This design will retain use of the existing objective lens, x-y stage, camera, and three interference filters.

A New Window in the Solar Spectrum: Infrared Array. The proposal submitted to the NSF to renew NOAO's contract for the next five years described in some detail the scientific objectives of solar research in the 1 - 5 μm spectral region. Three of the most promising areas are summarized briefly here.

Because the ratio of Zeeman splitting to thermal line width increases linearly with wavelength, it is possible using Zeeman sensitive infrared lines to measure weaker magnetic field strengths than is possible at visible wavelengths. Infrared magnetic observations offer the prospect of investigating directly the 20 year old question of the distribution of field strength in magnetic elements outside sunspots. The interpretation of existing data has been hampered by low spatial resolution and (to date) an absence of spatial coverage. With an infrared array camera in conjunction with the McMath main spectrograph and polarizing optics, it will be possible for the first time to make infrared spectromagnetograms that cover one square arcmin with two arcsec spatial resolution.

The solar atmosphere is more transparent at 1.65 μm than at any other wavelength. Although the \( \tau_{1.65} = 1 \) level is only 40 km below the base of the visible photosphere, this is precisely
the region in which convection and radiation contend most strenuously for dominance. The nature of the convection that produces the solar granulation must be inferred at visible wavelengths by the indirect effects of convective "overshoot" into the convectively stable photosphere. With near infrared observations, we can study granular convection where its influence is more direct. Also, because of the well understood opacity (dominated by H free-free absorption) and the nearly Rayleigh-Jeans intensity distribution (linear in temperature), the interpretation of continuum observations is more straightforward in the infrared than in the visible.

The infrared offers a sensitive probe of the temperature minimum region at a height of about 500 km. This transition to the rising temperatures of the outer atmosphere is central to the problem of understanding nonradiative heating in the solar chromosphere and, more generally, to the problem of understanding why some stars have chromospheres and others do not.

The CO molecule, with vibration-rotation bands at 2.3 μm and 4.7 μm is a good thermometer for the temperature minimum because it dissociates strongly above 4000 K. T. Ayres (U. of Colorado) has proposed that CO also plays an active role as the dominant cooling mechanism near 4000 K. He hypothesizes that the joint effect of cooling by CO and H is to produce a thermally unstable regime between 4000 K and 5000 K, with the result that the atmosphere bifurcates into hot and cool components. Evidence for this picture has been presented by Ayres, L. Testerman (Los Alamos), and J. Brault using observations with the 1-m FTS at the McMath telescope. Direct observation of the hot and cool components, and their identification with atmospheric features at other wavelengths, will require high resolution CO spectroheliograms to supplement the very accurate but spatially coarse, single point FTS measurements.

Another interesting feature of the CO fundamental bands is their strong five-minute intensity oscillations (up to 7% full amplitude), which have been little explored since initial observations of Noyes and Hall.

The goal of this program is to construct a second infrared camera. The existing camera is the most heavily oversubscribed of all the instruments available for use at Kitt Peak and simply cannot meet the demand for use from solar and nighttime astronomers. The costs and the use of the second infrared camera would be shared between KPNO and NSO. The estimated cost of construction, including acquisition of a new detector, is estimated at $250K. A major capital item is the detector; other capital expenses are the dewar, electronics and optical filters. These costs are being split by the nighttime and daytime programs; the NOAO Infrared Group will provide manpower.

Synoptic Velocity Studies: Spectromagnetograph. This project is part of an ongoing NSO effort to provide a modern two-dimensional detector and real time data processing system for the calibrated measurement of solar magnetic and velocity fields at the Vacuum Telescope on Kitt Peak. In contrast to the two slit modulation used by the current 512-Channel Magnetograph, the Spectromagnetograph will separate changes in line shape from line position so that thermodynamic, velocity, and magnetic variations in space and time can be properly measured and compared. The instrument will thus become a powerful new tool for study of the magnetohydrodynamics of the Sun over a wide range of temporal and spatial scales.

In addition to improving the reliability and interpretability of the daily synoptic data, the added capabilities of the Spectromagnetograph are crucial for study of the coupling of thermodynamic with magnetic structure in the upper photosphere and chromosphere; for quantitative measurement of flux changes resulting from emergence, submergence, and interactions of isolated magnetic regions; and for detecting rapid flare related velocity and magnetic field changes, which are inseparably confused with intensity variations in current
detector systems. The real time image processing capabilities of the data system will also serve as the heart of a High Degree Helioseismograph (see project described below) for fundamental studies of convection zone dynamics in the Sun. Finally, the added spectral range spanned by the two-dimensional detector will make practical simultaneous continuum photometry for comparison with solar irradiance measurements, and the detector and analysis system could readily be adapted for use as a video magnetograph with addition of a birefringent filter and optical components.

All capital items have already been purchased. A programmer will be required in FY 1989 to complete the project.

Global Oscillations: High Degree Helioseismograph. The goal of this project is to provide an instrument to obtain observations of high degree (short wavelength) acoustic p- and f-modes. The observations would be made regularly, but not continuously, for a period of years and would be made available to the community through a data archive. GONG will measure moderate degree modes. The High Degree Helioseismograph will utilize K- intensity images. The scientific goal is to study the hypothetical variation of p-mode frequencies associated with activity cycle variations in the convection zone. The instrument would allow unique studies of how the convection zone structure changes during a solar cycle. The instrument would also be used for studies of the internal structure of sunspots and active regions by using the newly discovered p-mode absorption phenomenon (discovered with the Vacuum Telescope). A search for predicted giant convection cells would also be possible.

The instrument will be used in conjunction with the Spectromagnetograph and will contain two television cameras based on the TI TC-241 CCD. One camera will image the full disk of the Sun while the other will be arranged to image simultaneously a field of view of nominally 488 x 754 arcsec. Both cameras will view the Sun through a K- interference filter that isolates a part of the atmosphere where oscillations in intensity are relatively strong.

The project is expected to take two years to complete.

Cluster Photometry: Stellar K-Line Filter. A systematic study of the rotation and activity cycles of a sizable sample of stars similar to the Sun would be extraordinarily useful in enhancing our understanding of the fundamental physics governing solar activity, particularly dynamo processes that are responsible for the generation of magnetic flux in the late-type stars. Present techniques for measuring stellar rotation and activity cycles are restricted to observing stars one at a time, a sequential procedure which is both slow and laborious. This project involves both a new observational strategy and a new instrument.

The new strategy is to observe, simultaneously, stars in clusters. Studies of open clusters have proven crucial in the verification and extension of the theory of stellar structure and evolution. Since it can be assumed in the first approximation that the stars in a cluster all have the same age and chemical composition, clusters provide homogeneous samples of objects which are especially suitable for studies of the nature of magnetic activity and cycles in solar-like stars.

The new instrument will consist of a photometric camera and a temperature stabilized, tunable, narrow band Ca II K-filter with sufficient field of view to image an area several arcmin in extent. A prototype filter has been designed by R. Dunn, and the optical components have been purchased. It is necessary to design and fabricate the mounting and temperature control systems for this filter and to integrate it with the UV enhanced TI CCD camera at the McMath. Following successful trials, the goal is to move the instrument to a telescope with larger aperture.
McMath FTS Servo Upgrade. The McMath 1-m Fourier transform spectrometer has been in operation since 1975. Well over 200 papers have been published on atomic and molecular energy levels, transition probabilities, and infrared spectroscopy as the result of work done at the FTS. A full upgrade of the FTS control servos is long overdue. The servo electronics are reaching, and in many cases have exceeded, their expected lifetimes. Spares for many of the components are no longer available. The main source of down time at the FTS is problems related to the servoelectronics, and it is becoming increasingly difficult to maintain the FTS in operating condition. Capital costs will be covered by outside funding.

C. Cerro Tololo Inter-American Observatory.

Summary of CTIO Projects

<table>
<thead>
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<th>Project</th>
<th>Non Payroll</th>
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<td>CCD Controllers</td>
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<tr>
<td>IR Controller/Acquisition system</td>
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<td>4-m Prime focus corrector</td>
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<td>4-m IR Photometer</td>
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CCD Controllers. The need for new CCD controllers is the consequence of several forces. Neither CTIO nor KPNO has enough controllers to operate the available CCDs on all the telescopes where they can be used simultaneously. To meet the demands of new scientific programs, particularly the imaging of very faint galaxies, it is necessary to provide for very low noise operation, high stability, excellent charge transfer efficiency and linearity, and improvements are possible relative to the performance of controllers currently in operation. In the future, the observatories will want to use CCDs with quad-readout and to make mosaics of large numbers of CCDs.

This project is ongoing, and the design is being coordinated with the interested groups in NOAO. Conceptual design should be completed within FY 1988.

IR Array Controller/Data Acquisition System. Data Acquisition at CTIO in the infrared is now carried out on two different computer systems, both in their declining years. Both the imager and upgraded IRS now require both Tolnet and the LSI/11. Furthermore, it is clear that additional software and hardware need to be developed to take full advantage of the capabilities of the SBRC arrays, as well as devices like the 10 µm IBC arrays that are expected to enter use in the next two to three years.

The system as proposed, will have as much of its higher level structure in common with other array applications (CCDs) as is practical. This work will be carried out jointly with the CTIO CCD controller project and in consultation with the Tucson IR and O/UV groups in order to ensure that this goal of maximum compatibility is reached. The new system is intended to handle all IR instrumentation now in use, and should be capable of handling larger or longer wavelength IR arrays when these are introduced. The user interface will run on the Sun workstations and will permit interaction with the instrument(s), the telescope, and the quick look data reduction facilities. Data display and quick look reduction will be done within the IRAF environment.

A detailed set of specifications will be determined through consultation with all the interested groups within NOAO during FY 1988, with fabrication during FY 1989.
4-m Prime Focus Corrector. The NOAO 4-m telescopes are currently equipped with prime focus correctors designed by C. Wynne. There are two correctors for each telescope, one for the blue and one for the red. This type of triplet corrector has very good images at its design wavelength. However, it has considerable chromatic aberration and is effective only over a limited spectral range. Use of these correctors at inappropriate wavelengths is probably the origin of the reputation that they have for producing mediocre images. They would be quite good if one were willing to change correctors between B, V, and R.

Wynne has suggested as an alternative a four element corrector similar in concept to the PF corrector designed for the Herschel Telescope. The addition of a fourth element allows chromatic aberration to be greatly reduced and makes an ADC useful. With new broad band anti-reflection multilayer coatings, the total light loss through the new corrector should be less than half that of the surfaces in the old corrector. Over wavelengths from 3650 to 8520 Å, the new design yields images with FWHM of less than 0.5 arcsec over the entire 50 arcmin PF field at all zenith angles up to 70° and less than 0.2 arcsec FWHM over a 30 arcmin field. The new corrector will have superb images over the entire area equivalent to that of a 2048 x 2048 Tektronix CCD, and very good performance over a mosaic of four such CCDs.

If this corrector proves to be as good in practice as appears likely, then KPNO will probably wish to acquire one for its 4-m telescope.

4-m IR Photometer. Introduction of the IR array imagers has significantly increased demand for the IR instruments. As a result, "light runs" of 20 nights have been scheduled during the present and coming semesters. We expect that upgrade of the IR Spectrometer with a similar array will only increase the demand. The principal bottleneck is the existence of a single adaptor box for use on both the 4-m and 1.5-m telescopes.

This project involves duplication of the basic photometer box. A second set of stepper motor drivers and duplicate power supplies would also be provided. Optical performance would be improved as well.

f/7.5 Secondary Mirror for the CTIO 1.5-m Telescope. The 1.5-m at CTIO has had a long history of imaging problems when used in the f/7.5 configuration. Under conditions of good seeing image sizes of less than 1.5 arcsec are never seen. In contrast, subarcsec performance has been obtained with the f/13.5 secondary. Hartmann testing of the telescope with the f/7.5 secondary shows that substantial amounts of spherical aberration are present. Since this is CTIO's second largest telescope, it is imperative that it provide the best imaging that we can obtain.

We are investigating the possibility of having the mirror refigured in the NOAO Optical Shop in Tucson. If this is not feasible, then it will be necessary to contract either the refiguring or the manufacture of a new mirror to a commercial vendor. If this proves necessary, then the project will be delayed because of lack of funds.

D. Central Computer Services.

<table>
<thead>
<tr>
<th>Summary of CCS Projects</th>
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54
Due to the budget cut, we have chosen to defer workstations activity until FY 1990. When adequate funding is granted we will provide modern data reduction facilities at the telescopes and in the observatory offices, with the installation of Sun systems. Computer users require more computer capacity to process larger volumes of data quickly, conveniently and correctly and the evolution of computer technology has accelerated to the point that systems are obsolete almost as soon as they are installed. Therefore, only a modest but continual program of upgrade and replacement will ensure the availability of reasonably current facilities.

During recent years this philosophy has led to the installation of Sun workstations at three of the telescopes at CTIO and two of the telescopes at KPNO. Sun workstations are also available at the Tucson headquarters building and in La Serena. Completion of this program for the telescopes at Kitt Peak requires Sun systems for the 1.3-m, the coudé feed, the #2-0.9-m, and the McMath. The system at the 1.3-m is required to provide data reduction for the IR imager. The coudé feed and 0.9-m systems are needed for data compression—one recent observing run looking for stellar oscillations required 200 tapes! The McMath requires a Sun for quicklook, data compression, and to break the bottleneck of downtown data reduction.

High priority must also be given to the integration of the Sacramento Peak computers, which include a Sun 4 server purchased in FY 1988, with modern networking to Tucson and the rest of the world. The key goals of these changes are to evolve toward distributed (networked) processing, flexibility, expandability, UNIX, interactive color image processing with IRAF, and more compatibility with Tucson computing facilities.

Networking has been completed at CTIO. At Kitt Peak, fiber optic coupling now links the 4-m and 2-m telescopes with the administration building.
VI. OPERATIONS AND MAINTENANCE

Operations and Maintenance

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<tr>
<td>Central Computer Services</td>
<td>676</td>
<td>291</td>
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<tr>
<td>Central Engineering &amp; Technical Services</td>
<td>549</td>
<td>297</td>
<td>846</td>
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<tr>
<td>Subtotal</td>
<td>9,329</td>
<td>5,470</td>
<td>14,799</td>
</tr>
<tr>
<td>USAF Support to NSO/Sunspot</td>
<td>(600)</td>
<td>(600)</td>
<td></td>
</tr>
<tr>
<td>NASA Support to NSO/Tucson</td>
<td>(54)</td>
<td>(54)</td>
<td></td>
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<tr>
<td>Total NSF Funding</td>
<td>9,329</td>
<td>4,816</td>
<td>14,145</td>
</tr>
<tr>
<td>Management Fee</td>
<td>405</td>
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</tr>
</tbody>
</table>

In this program category we include the cost of operating and maintaining NOAO facilities—both office complexes and telescope facilities, providing associated user support, and supporting NOAO's scientific and administrative activities. For convenience this chapter has been divided into three sections: (A) Telescope Operations and User Support, (B) Major Facility Maintenance, and (C) Program Support.

A. Telescope Operations and User Support.

This program plan emphasizes new instrumentation and programs, and properly so since it is important to call attention to changes in program direction. The goal of all of these initiatives, however, is to put new observing capability in the hands of the user community. New instruments can be effective only if the telescopes that feed the light to them operate reliably and do not compromise instrumental performance. New instrumentation often places new demands on old telescopes for improved tracking, offsetting, image quality, rastering, etc. Consequently, we must constantly engage in a program of upgrading existing facilities. We must also provide adequate staffing to maintain, calibrate, and set up increasingly complex instrumentation and tutor astronomers in its effective use.

All three of the observatories within NOAO have an enviable reputation for the quality of the service that they provide to the user community. The standards for this service have been maintained to a substantial degree despite reduced staffing levels and operating budgets. Limitations on the number of instruments provided, block scheduling, closure of some smaller telescopes, and shutdown during the summer at Kitt Peak, have allowed the observatories to continue to operate what remains at acceptable levels of reliability. Nevertheless, signs of stress are apparent at all three sites, and it is clear that additional reductions in support must result in closure of facilities.
B. **Major Facilities Maintenance.**

The budget cuts of the past few years, combined with the reprogramming of funds toward major initiatives such as the development of technology for the next generation of telescopes and the construction of the GONG network, have left us with some serious maintenance problems that must be corrected. A comprehensive list of these problems follows, but again in FY 1989 nearly all maintenance must be deferred.

1. **Kitt Peak.**

At Kitt Peak the roads must be chipped and sealed. If maintenance is deferred and the roads continue to deteriorate, then the cost of repaving will be significantly more than the estimated $60K required to repair them this year. The painted exterior of the McMath solar telescope is an eyesore and is continuing to deteriorate. In addition, the interior of the McMath, which was last painted in 1978, now needs attention. The cost estimates for labor, materials, and equipment, in 1988 dollars, are $120K for the exterior, and $65K for the interior. The 4-m telescope, last painted in 1980, is also beginning to lose its paint. In order to minimize the cost involved, it should be painted immediately. The estimated cost to prepare, prime, and paint the exterior of the dome, shutter, and upper 30 feet of the building is approximately $65K.

One project viewed as important but not critical is the upgrading of the fire protection system. With the advanced features of the AT&T telephone system on Kitt Peak, it is now possible to purchase a fire alarm system capable of monitoring the entire mountain. In view of the reduced staffing level, this is a very desirable option.

2. **Sacramento Peak.**

During FY 1988, a PCB transformer in the Vacuum Tower Telescope at Sacramento Peak was replaced but all other facilities maintenance, repairs, and refurbishment were again deferred.

NSO staff have conducted a survey of asbestos containing materials and are in the process of determining whether or not any of the additional transformers at Sacramento Peak contain PCB. A study of major water and propane leaks that have occurred during the past ten years is in progress in order to determine the most economical way to proceed with a plan to abate this safety and health hazard.

The yard lines for the 21 relocatable houses have been the source of one half of the propane leaks. A budget planning quote is being obtained from a local contractor for replacing these lines, and the cost is likely to be at least $30K. Other yard lines and the gas mains should be replaced in future years.

The water mains between the ground level storage tanks and the overhead tank and a main which serves the facilities maintenance and one housing area have surfaced as being a major problem. These 6-inch lines have poured lead joints which have been stressed over the years and should be replaced. Our estimate for this replacement project is $35K.

The safety program needs funding for respirators, asbestos removal supplies, and special vacuum cleaners, etc.; and for physical examinations, training, and other miscellaneous items.

Maintenance and improvement items listed last year and needed even more badly now are:

1. Reroof machine and electronics shop building ($30K). Although this building has a metal roof it has multiple leaks in the "flat" roofed area. Ceilings are being damaged and
cannot be repaired while the leaks continue. The only feasible solution is to install a pitched roof over the "flat" area. This will also allow us to provide adequate insulation for this building, which is also expensive to heat.

(2) Paint machine and electronics shop ($5K). This building was painted by us about seven years ago but is now streaked, faded, and is an eyesore.

(3) Reroof the 48-inch Telescope building ($20K). This roof has several bad leaks and damage is occurring to ceilings and floors. We have repeatedly tried to patch the roof and stop the leaks but to no avail.

(4) Paint 48-inch Dome ($18K). We do not know the age of the existing paint on this dome but the paint is rapidly changing from white to rust.

(5) Paint Main Lab ($10K). The main lab building looks horrible! Since it is central to the operation of Sacramento Peak and is viewed by tourists, visitors and staff, it is essential that this shoddy appearance be changed.

(6) Paint Sacramento Peak Vacuum Tower Telescope building ($20K). The paint is flaking and rust streaks are very evident on NSO/SP's premier telescope building. Like the Main Lab, this building is viewed by everyone.

(7) Paint Facilities Maintenance buildings ($10K). The shop buildings have a very shabby appearance. It will enhance the morale of our maintenance staff to make their work area more presentable.

(8) Resurface roads, driveways and parking lots ($75K). Except for pothole patching, no maintenance has been performed on roads and driveways during the past 20 years. The present surface (where it exists) is very thin and brittle with the edges gone in many places.

(9) Fire alarm system ($110K). At the present time only the VOQ, Main Lab, and Big Dome buildings have an automatic alarm system but this system is "prehistoric." It was installed years ago by the USAF who maintained a professional firefighting crew at the fire station. We now have a volunteer fire crew who cannot always hear the existing siren from their houses. So, our protection, particularly at night, is very minimal.

(10) An extension to the main lab is drastically needed to provide additional office space and adequate room for data reduction equipment. There is an urgent need for a building which would provide weather-tight storage for furniture, equipment, and supplies as well as parking for vehicles. In addition, a community recreation building has long been needed at Sunspot as is a visitor center to accommodate more adequately the increasing flow of public visitors.

3. Cerro Tololo.

The pipeline bringing water to the summit of Tololo from the valley 4,000 feet below has begun to decay, and several long sections now have leaks. The source of the decay has been identified as a bacterium, and there is no alternative but to replace the pipe. This work will be carried out over a three year period, beginning with the expenditure of $25K for pipe in FY 1989 to replace that section which is most deteriorated.

The most pressing need for facilities improvements in Chile is for replacement of two corrugated metal buildings on Tololo which house the electrical generator and switching plant,
and the metal shop and warehouse. These were constructed over 20 years ago, and are now in disrepair. Unfortunately, they are a safety hazard since rain consistently gets into the buildings and causes electrical shorts.

4. Tucson Headquarters.

The NOAO Tucson headquarters building is in need of major exterior stucco repair. The majority of the work is centered on the Engineering wing which was added in 1966. Extensive cracking and peeling of the stucco have occurred over the past few years. Unless the exterior is stabilized, the future cost of repair will greatly exceed the current estimate of $25K. All of the paved areas serving the headquarters building need attention. The current plan is to chip and seal the parking areas, and pave the maintenance area. The estimated cost for both areas is $40K.

The need for additional space in the NOAO Tucson Headquarters has become critical. The GONG project requires about 7,000 square feet to house its staff and computer systems beginning in FY 1990, with smaller amounts of space required before then as the staff ramps up. The analysis and distribution of data is essential to the success of the GONG project, and the need for a data center will continue for several years after observations have been completed. The scope of this effort is not trivial. In addition to the mainframes and peripherals, the GONG Data Management and Analysis Center will have of the order of 10 Gigabytes of hard disk and must provide ready access to a data archive containing 1,800 tapes, 500 optical disks, and two "juke boxes" to handle the online portion of the archive. In total, it will be necessary to store five terabytes of data. No funds were included in the GONG proposal itself to provide space for this center.

C. Program Support.

The several units which support NOAO's scientific program are discussed below.

1. Director's Office.

The Director is responsible for providing scientific leadership for NOAO, determining priorities, allocating resources, budgeting, and planning. The divisions reporting to the Director are: CTIO, KPNO and NSO; each is headed by an Associate Director of NOAO. The position of Deputy Director of NOAO was added. This person, P. Osmer, acts for the Director in her absence from Tucson. The position of Associate Director of Kitt Peak National Observatory was eliminated. D. De Young became the Associate Director of NOAO for KPNO. While the organization as such remains the same, AURA's action made permanent the cost saving which was first realized when S. Wolff held the positions of Associate Director of NOAO for KPNO and Acting Director of NOAO--and continued when she remained "acting" at KPNO after her appointment as Director of NOAO. One management position was saved and this saving continued because De Young's management position in KPNO was not refilled after his appointment as Associate Director of NOAO for KPNO. The appointment of Osmer as Deputy Director did not require a new position because he continues to occupy his present position on the tenured scientific staff.

The Director's Office manages funds for staff travel, for the AURA Observatories Visiting Committee, and the NSF Foreign Telescope Travel Fund--a special account set up to help defray travel expenses for U.S. observers who have been assigned observing time on specified large foreign telescopes.
2. **Central Facilities Operations.**

CFO provides essentially all the direct and indirect support services necessary for the operational needs of the NOAO Tucson headquarters buildings. The services provided are quite broad in scope. They include, but are not limited to, maintenance of the headquarters buildings and their physical plant, transportation services, safety, security, mailroom and general supplies, custodial, and groundskeeping. In addition, facilities design and construction support is rendered to the Kitt Peak mountain facilities as required.

3. **Central Administrative Services.**

CAS provides support services to the research programs in the areas of financial management, procurement, personnel, shipping and receiving, property management, and contract administration.

The controller’s office is responsible for establishment and implementation of financial and administrative standards and procedures throughout NOAO, involving coordination with the Associate Directors and Unit Heads in the development of budgets and plans. This office also monitors performance against the approved budget and advises the Director of potential problems.

The accounting department provides full bookkeeping, data processing, disbursement, payroll, and financial reporting services for all NOAO units except for certain transactions occurring in Chile. The latter are performed by CTIO’s La Serena and Santiago business offices and reported monthly to accounting for inclusion in consolidated records and reports. The accounting department budget includes the cost of liability and fidelity insurance for all NOAO activities.

The personnel department develops, implements, and coordinates personnel policies and programs for NOAO. It is responsible for recruitment, relocation assistance, wage and salary administration, equal opportunity employment and affirmative action, and employee benefits for all NOAO personnel other than local hires in Chile.

The procurement department provides subcontracting, purchasing, expediting, and shipping/receiving services for all NOAO units except for local purchases by CTIO in Chile. It also arranges for the export of supplies and equipment purchased within the U.S. for delivery to CTIO and coordinates shipments through a number of freight forwarders. In addition, it serves as CTIO’s main communications link to the U.S., providing voice radio, teletype, and electronic mail services.

4. **Publications and Information Resources.**

Formerly the Public Information Office, the Office of Publications and Information Resources (PIR) began operation under its new title and Manager on 1 January 1988. The PIR office has the dual responsibility of responding to requests from the media for support and information, and of assisting with the preparation of printed materials, i.e. newsletters, brochures, policy manuals, proposals and plans for the NSF. In addition, this office serves as NOAO’s primary point of contact with the general public, film producers, and other interested parties. The Manager of PIR also oversees and supervises the on-premises Printshop and other reproduction activities. The staff of this office has been reduced by one.
5. Engineering and Technical Services.

ETS is organized into: a) project style groups that have long-term assignments to specific project objectives, and b) general services groups that provide limited, short-term services on a first-come-first-serve basis. General services is intended also to maintain basic equipment and facilities for usage by people assigned to the project groups. General services includes the engineering manager's office and those engineering specialists who are not assigned to a project group. Costs related to the project groups are shown where the projects actually occur. The ETS costs shown in this chapter reflect the general services costs. This office also oversees the NOAO coatings lab.


CCS is responsible for policy development with respect to computer languages and hardware acquisition, for planning for the application of new and developing technology within NOAO, for monitoring the state-of-the-art in computer applications to astronomy, and for the development of major software systems for application to data reduction and analysis.

CCS personnel provide support for data reduction and analysis, operate and maintain the NOAO Tucson offices computers and their operating systems, and provide general purpose programming support for scientific, engineering, and some administrative activities.

In FY 1989 the several workstations acquired in FYs 1986 - 1987 will be fully implemented and optimized for reduction and compression of large image data sets at five major CTIO and KPNO telescopes. However, extension of the workstation implementation to other telescopes, and completion of an intercomputer network will be deferred indefinitely. One or more of the VAX 11/750 computers will be closed, and the others taken off maintenance contract as part of a strategy to reduce O&M costs.

The CCS staff will continue to support the pre-release distribution of IRAF (Image Reduction and Analysis Facility) software to over 150 community sites. Work will continue on major systems software, giving highest priority to developments required to enhance the effectiveness of IRAF for general image processing. Several applications packages for reduction of NOAO data will be added to IRAF during the year.

NASA funding has been requested for IRAF ports to new computers, for limited on-site IRAF support to the community, and for development of a prototype remotely accessible database of observation headers. The proposal is currently under review at NASA headquarters.
VII. BUDGET

As noted in the introduction, the budget required to maintain the level of activity described in the FY 1988 Program Plan submitted before the budget was reduced by nearly $3.0M is $2.4M higher than requested by the President in his submission to Congress. The budget of $26.8M was obtained by projecting expenses for currently authorized positions with salaries increased by 4% in FY 1988 (an increase that has not yet been granted) and by 5% on 1 April 1989, which is the date on which annual increments are normally made. Cuts made in non-payroll funding in FY 1988 were restored. GONG was increased by $500K to $1.5M, since NSF's own planning documents assume this increase; in order to support acquisition of the hardware for the six sites of the GONG network, an annual rate of expenditure of $2.5 - $3.0M would be required. The only other real increases in the budget are to support greater costs of health and liability insurance, to accommodate unfavorable changes in the peso/dollar exchange rate in Chile, and to begin purchase of the new Palomar Sky Survey for both Tucson and La Serena.

In order to reach the budget level of the President's request it is necessary to reduce the budget by at least 10%, and since apart from GONG there are no programmatic increases in the budget, this reduction must be applied to ongoing programs. There are two ways to approach these reductions. They can be made across the board so that all programs are continued but at a reduced level, or the reductions can be made selectively, with some programs eliminated entirely but others continued at a vigorous, or at least at a moderately healthy, level.

An across the board cut at the 10% level is extremely damaging to all programs. Estimates made by the Associate Directors are that a reduction of this amount would have the following consequences: facilities that produce about half the papers from NOAO would be closed; access to observing facilities by graduate students and post docs would be severely restricted by virtue of competition for observing time at the few facilities remaining open; none of the outstanding problems with inadequate funding for purchase of new hardware for instrumentation, new computer systems, and facilities maintenance would be solved. Scientific staffing levels would not be increased at Sacramento Peak and would be reduced at CTIO and KPNO. Because certain core areas of support, such as maintenance of mountain facilities and some central administrative functions, scale only slowly with the number of users, the ratio of expenditure for various overhead functions to expenditure for science would increase.

One of the primary problems with the current program is that over the years it has expanded and fragmented; if resources were focused on fewer activities, those resources could be used to greater effect. In real terms, corrected for inflation, the budget is smaller than it has been at any time since 1964. In that period of time, NOAO has put into service two 4-m telescopes, undertaken the operation of Sacramento Peak, added the vacuum telescope on Kitt Peak, undertaken the development and distribution of IRAF, become actively involved in the development of technology for the next generation of large telescopes for solar and especially nighttime astronomy, been charged with support of the mirror-casting work at the Steward Observatory Mirror Laboratory, begun work in such advanced technologies as adaptive optics and interferometry, and with active community support initiated the GONG project.

All of these programs are important to the future of astronomy, but it is clear that NOAO can no longer support them all. This becomes particularly apparent if runout costs are taken into consideration. Many ongoing programs require a substantial ramp up in funding in order to guarantee successful completion. GONG, the mirror casting, adaptive optics, and the distributed array for interferometry all fall in this category. Claims for increased funding for these efforts will have to be confronted on about the same time scale as increased funding.
must be sought for the construction of 8-m telescopes and for participation in LEST or an equivalent solar facility.

Recognizing these problems, NOAO, AURA, the NSF, and the community have reviewed the NOAO program and have recommended priorities for the national observatory. Setting priorities must necessarily involve saying no to many good ideas. The program plan as submitted emphasizes continued operation of existing facilities, but provides for development of GONG, for work on preparation of a proposal to place 8-m telescopes in Chile and on Mauna Kea, for polishing and developing thermal control and support systems for a 3.5-m borosilicate blank as a technology demonstration, and for maintaining development of focal plane instrumentation at the current rate.

In order to accommodate these activities, other programs have been greatly reduced or eliminated. Specifically, the Advanced Development Program has been eliminated as an independent division of NOAO. Support of the development of a prototype interferometric array has been stopped; a scientific position in interferometry has been eliminated, the gratings lab has been permanently closed, and engineering support has been reduced. A senior KPNO scientific staff position has been eliminated, support for travel and page charges for visiting observers has been dropped, although support will be provided for travel by students who are using the telescopes for thesis research and at the directors’ discretion for cases of extreme hardship. The light pollution program will no longer be funded, and there will be a reduction in support for central administrative services and for operation of the Tucson buildings.

NOAO proposes to provide funding for the Steward Observatory Mirror Laboratory through June 1989. These funds will permit completion of a 3.5-m casting and the beginning of work on larger castings. NSF has indicated that it prefers in the future to receive a separate proposal from Steward for continued funding, and by providing support for 12 additional months, NOAO hopes to guarantee an orderly transition for this essential program.

Since the savings in FY 1989 from reduced NOAO funding of the Mirror Laboratory are small, NOAO will adopt a number of temporary measures, including deferring (yet again!) major facilities maintenance and computer purchases; non-payroll funds will not be increased to compensate for inflation, although provision has been made for a pay increase. Several positions, including six scientific staff positions that are currently vacant, will be frozen.

In the past, various committees including the Observatories Visiting Committee, have called attention to the inadequate funding for the NSO programs as currently defined, particularly at Sacramento Peak. Despite this long standing problem, NSO has indicated a preference for across the board cuts in its program but continued operation of all facilities. Because each of the NSO facilities offers unique capabilities, the NSO staff argue that the consequence of closing any one of them would be the loss of an entire area of research. Because of the serious issues involved, NOAO and AURA have accepted this recommendation for FY 1989, but have asked NSO to develop a long-term program for solar physics within NOAO that provides for a viable NSO under various assumptions as to future budget levels. This plan would be implemented in early calendar year 1989 to meet the level of funding provided within the President’s budget request to congress for FY 1990.

In parallel with this activity, CTIO and KPNO will also be asked to prepare long range plans to accommodate the evolution of their facilities to the next generation of larger telescopes. Again, the planning will take into account various budget levels, including level funding. The KPNO and CTIO plans will serve as a guide in determining which projects will be undertaken in collaboration with the various universities that have approached NOAO about joint construction projects.
If the budget in future should fall below the $24.4M included in the President’s request for FY 1989, then much more drastic actions will have to be taken. An inevitable consequence would be the closure of telescopes at CTIO, KPNO, or NSO. The various options with the associated cost savings have been discussed with the NSF, but priorities among these options have not yet been selected.

It is clear that this plan represents major changes in the program of NOAO. The elimination of ADP and the departure of several staff associated with that program will have the inevitable consequence that NOAO will cease to play a key role in the development of such technologies as interferometry and adaptive optics for nighttime astronomy. Work on 8-m telescopes will be held at a very low level until such time as construction funds become available, and NOAO is thereby betting its future in this area on the capability of industry, universities, and other telescope construction projects to develop the necessary technology. By its choice not to close telescopes now in order to purchase the materials to make 8-m mirrors, NOAO has delayed completion of the national 8-m by at least two years.

These choices, painful as they may be, appear preferable to the alternative of greatly reducing access to what are at the present time, for both solar and nighttime astronomy, the best available observing facilities. It is also true that recent advances in instrumentation have dramatically increased the scientific capability of the telescopes now in service. The quality of research in this country is determined more by the creativity and imagination of astronomers than by the aperture of the telescopes that they use. While NOAO must continue to work actively to build the next generation of telescopes for both solar and nighttime astronomy, we have chosen a pace for that work that will permit the national observatories to provide continuity in their support of community of observers that have come to rely on the facilities that we provide.
APPENDIX 2

NOAO Management

S. Wolff  Director, NOAO
R. Barnes  Assistant to the Director
J. Beckers  Director, Advanced Development Program/
    Associate Director, NOAO
G. Blevins  Manager, Central Administrative Services/
    Controller
L. Daggert  Manager, Engineering & Technical Services
D. De Young  Associate Director of NOAO for KPNO
D. Graham  Head, Central Facilities Operations
F. Hegwer  Assistant to the Director, NSO
J. Kennedy  Assistant to the Director, NSO
J. Leibacher  Director, National Solar Observatory/
    Associate Director, NOAO
P. Osmer  Deputy Director of NOAO
S. Ridgway  Manager, Central Computer Services
Y. Sharp  Administrative Aide to the Director, NOAO
R. Smartt  Deputy Director for NSO/SP
P. Williams  Manager, Publications & Information Resources
R. Williams  Director, Cerro Tololo Inter-American Observatory/
    Associate Director, NOAO
APPENDIX 3

Scientific Staff: Primary Fields of Interest and Recent Publications

ADVANCED DEVELOPMENT PROGRAM

J. Beckers - Atmospheres of stars, interferometry of stars and Seyfert nuclei, structure of the solar atmosphere, NTT.


J. Christou - High spatial resolution optical and infrared interferometric imaging, red supergiants.


D.L. DePoy - IRAS sources; star formation in galaxies, infrared spectra of galaxies.


I. Gatley - Infrared studies of star formation; infrared studies of the Milky Way; morphology of star forming regions.


J. Goad - Dynamics of galaxies, NTT.


L. Goad - Planetary nebulae, galaxy dynamics; digital image processing, astronomical instruments.

E. Kibblewhite - Design of telescopes and instrumentation; interferometric imaging; data handling and analysis techniques; large area sky surveys; galaxy photometry; galaxy kinematics using secular parallax.


M. Merrill - Infrared observations, IR detector technology, seeing studies, NTT.


CERRO TOLOLO INTER-AMERICAN OBSERVATORY

V. Blanco - Low dispersion spectra of late type stars in the galactic center and Magellanic Clouds, photometry of variables in Baade's window.


O. Eggen - Photometry and astrometry; dynamical evolution of the galaxy.


J. Elias - IR photometry and instrumentation; star formation.


D. Geisler - Abundances and properties of star clusters in the galaxy and nearby galaxies.


B. Gregory - Low temperature physics and infrared instrumentation.


S. Heathcote - Interstellar medium; planetary nebulae, Herbig Haro objects; star formation; supernovae, polarisation of active galactic nuclei.


T. Ingerson - Electronics, computers, and optics.


A. McWilliam - Stellar spectroscopy; isotopic compositions, blue straggler stars.


M. Phillips - Active galactic nuclei; supernovae.


N. Suntzeff - Stellar abundances and populations.


D. Terndrup - Stellar populations; photometry; reduction software.


A. Walker - Stellar photometry; Cepheid variables; open clusters.


W. Weller - Telescope instrumentation, spectra of emission-line stars.


R. Williams - Novae; accretion disks; radiative transfer; supernovae; galaxy surface photometry.


KITT PEAK NATIONAL OBSERVATORY

H. Abt - Stellar spectroscopy; binary stars; stellar rotation.


T. Armandroff - Stellar populations in the galaxy and nearby galaxies; globular clusters; dwarf spheroidal galaxies; massive stars, the stellar luminosity function, the initial mass function; population II variable stars.


D. Backman - IR and visual photometry, coronagraphy and spectroscopy of stars with orbiting solid material.


S. Barden - Instrumentation; binary stars.


M. Belton - Planetary spectroscopy; theory of planetary atmospheres.


R. Ciardullo - The dynamics of superclusters; observations of novae of M31; planetary nebulae in early type galaxies; emission regions in galaxies with active nuclei.


D. Crawford - Photoelectric photometry; galactic structure; telescope construction.


R. Davies - The dynamics and stellar populations in early type galaxies; the stellar component of active galaxies.


D. De Young - Theoretical astrophysics; active galaxies and QSOs, galaxy clusters; astrophysical plasma processes and hydrodynamics.

J. Frogel - Infrared properties of cool stars and stellar systems.


D. Godfrey - Dynamical meteorology of the outer planets.


Richard Green - Quasars; white dwarfs; extragalactic astronomy.


K. Hinkle - Infrared spectroscopic studies of late-type and variable stars.


G. Jacoby - Local group galaxies; stellar populations; planetary nebulae.


R. Joyce - Infrared photometry and spectrophotometry of regions of star formation.


T.D. Kinman - RR Lyrae variables, planetary nebulae; globular clusters; dwarf and emission-line galaxies; photometry of QSOs and BL Lac objects.

R. Lynds - Observational cosmology; galactic morphology.

AAS abstract: "Giant Luminous Arcs in Galaxy Clusters," B.A.A.S., 18, 1024.

P. Massey - Wolf Rayet stars; stellar spectroscopy.


P. Osmer - Spectroscopy and space distribution of quasars.


C. Pilachowski - Stellar abundances and evolution; chemical composition of globular cluster stars; chemical evolution of the galaxy.


A. Porter - Clusters of galaxies; cD galaxies; surface photometry; supernovae; cool stars.


R. Probst - Infrared astronomy; instrumentation.


S. Ridgway - High-resolution spectroscopy of late-type stars; infrared spatial interferometry.


L. Wallace - Temperature structures of outer planets.

S. Wolff - Stellar atmospheres; stellar activity; star formation.


NATIONAL SOLAR OBSERVATORY

R. Altrock - Corona, granulation.


J. Brault - High resolution and laboratory spectroscopy.


R. Dunn - Image restoration, instrumentation.


B. Durney - Dynamo theory, rotation, convection.


T. Duvall - Helioseismology, large scale magnetic fields and flows.


M. Giampapa - Solar and stellar activity.


D. Haber - Solar oscillations and their interaction with magnetic fields and flares.


J. Harvey - Solar and stellar magnetic and velocity fields.


F. Hill - Helioseismology, convection, large scale flows, atmospheric waves.


R. Howard - Rotation, large scale magnetic and velocity fields, sunspots.


J. Jefferies - Radiative transfer, structure of solar atmosphere.

H. Jones - Magnetic fields, faculae, radiative transfer.


S. Keil - Granulation, atmospheric waves.


S. Koutchmy - Coronal structures, magnetic fields, high resolution imaging.


J. Leibacher - Helioseismology, atmospheric dynamics.


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D. Neidig - Flares, active region dynamics.


L. November - Helioseismology, image restoration, convection.


A. Pierce - Gravitational redshift.


D. Rabin - Magnetic fields, structure of upper atmosphere.


R. Radick - Solar and stellar activity, image restoration.


G. Simon - Magnetic fields, supergranulation, oscillations.


R. Smartt - Prominences, corona, magnetic fields, instrumentation.


M. Smith - Solar and stellar activity, oscillations.


J. Zirker - Magnetic fields, prominences.


CENTRAL COMPUTER SERVICES

N. Sharp - The distribution, formation and dynamical evolution of galaxies, binary galaxies and galaxy clusters.


"Supercomputers in Optical Astronomy," in The Use of Supercomputers in Observational Astronomy, ed. T.J.Cornwell, NRAO workshop no. 15

F. Valdes - Cosmology, molecular clouds, SETI, automated image analysis, astronomical software development.


R. Wolff - Spectroscopy; instrumentation; applications of computers to instrumentation and telescope control.
APPENDIX 4

NATIONAL OPTICAL ASTRONOMY OBSERVATORIES
USER STATISTICS1
FY 1987

VISITOR TELESCOPE USAGE

<table>
<thead>
<tr>
<th>Visiting Observers</th>
<th>CTIO2 U.S. Foreign</th>
<th>KPNO3 U.S. Foreign</th>
<th>NSO4 U.S. Foreign</th>
<th>NOAO U.S. Foreign</th>
<th>TOTALS Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astronomers</td>
<td>144 79</td>
<td>402 31</td>
<td>126 20</td>
<td>672 130</td>
<td>802</td>
</tr>
<tr>
<td>Graduate Students</td>
<td>32 12</td>
<td>130 2</td>
<td>7 0</td>
<td>169 14</td>
<td>183</td>
</tr>
<tr>
<td>Other (technicians, research assistants, etc.)</td>
<td>3 14</td>
<td>0 2</td>
<td>0 16</td>
<td>3 19</td>
<td></td>
</tr>
<tr>
<td>Total Visitors</td>
<td>176 94</td>
<td>546 33</td>
<td>135 20</td>
<td>857 147</td>
<td>1004</td>
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<tr>
<td>Institutions</td>
<td>56 25</td>
<td>93 17</td>
<td>44 14</td>
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</tbody>
</table>

1 The figures in these tables reflect the number of observers/users physically present at the Observatory and also include multiple visits by a single observer/user. These tables do not include NOAO staff.

2 During fiscal year 1987, a total of 221 observing programs were carried out by visitors and the NOAO staff at Cerro Tololo. Visiting astronomers were assigned 78% of the scheduled telescope time and the remaining 22% was assigned to the staff.

3 During fiscal year 1987, a total of 315 observing programs were carried out by visitors and the NOAO staff at Kitt Peak. Visiting astronomers were assigned 78% of the scheduled telescope time and the remaining 22% was assigned to the staff.

4 During fiscal year 1987, a total of 151 observing programs were carried out by visitors and the NOAO staff at the National Solar Observatory. Visiting astronomers were assigned 76% of the scheduled telescope time and the remaining 24% was assigned to the staff.

VISITOR REDUCTION FACILITIES USAGE

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<tr>
<td>Number of Institutions</td>
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</tr>
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<td>Grant Comparator - 2 axis</td>
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<tr>
<td>PDS Microdensitometer</td>
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*The numbers reflected above show duplicated usage of NOAO-Tucson reduction facilities by visiting scientists. NOAO staff are not included in these figures.
**APPENDIX 5**

**TABLE I**

**FUNDING BY SOURCE**

(Amounts in Thousands)

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**STAFFING SCHEDULE**

(In Full Time Equivalents)

| NSF Funded | 63.20 | 72.55 | 316.56 | 452.31 | 465.71 | 466.21 |
| Non-NSF Funded | 9.75 | 9.75 | 8.65 |
| Total | 462.06 | 475.46 | 474.06 |

1 FY-1988 Program Plan, Revision 1.
2 Includes $825K new funds for UA mirror development contract.
3 Estimated amount only; cannot be determined at this time.
### TABLE I-A

**ADDENDUM TO FUNDING BY SOURCE TABLE**

(Amounts in Thousands)

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<th>FY-1987</th>
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<td>Utilities &amp; Communications</td>
<td>Purchased Services</td>
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<th>STAFFING SCHEDULE</th>
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<tr>
<td>(In Full Time Equivalents)</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Scientists</td>
</tr>
<tr>
<td>Engineers &amp; Scientific Programmers</td>
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<tr>
<td>Administrators &amp; Supervisors</td>
</tr>
<tr>
<td>Clerical Workers</td>
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<tr>
<td>Technicians</td>
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<tr>
<td>Maintenance &amp; Service Workers</td>
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<td>Total</td>
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## TABLE III

**Scientific Staff & Support**

(Amounts in Thousands)

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<th>PNO</th>
<th>SUNSPOT</th>
<th>TUCSON</th>
<th>FTT</th>
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<th>TOTAL FY-1989</th>
<th>TOTAL FY-1988</th>
<th>TOTAL FY-1987</th>
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<tr>
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### Staffing Schedule

(In Full Time Equivalents)

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<th>PNO</th>
<th>SUNSPOT</th>
<th>TUCSON</th>
<th>FTT</th>
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## TABLE IV
### INSTRUMENTATION
(Amounts in Thousands)

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### STAFFING SCHEDULE
(In Full Time Equivalents)

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<th>GONG</th>
<th>FIT</th>
<th>CENTRAL OFFICES</th>
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OPERATIONS & MAINTENANCE BY COST CATEGORY
(Amounts in Thousands)

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<th>SUNDPSOT</th>
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<th>TOTAL FY-1988</th>
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<td>2,315</td>
<td>2,355</td>
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<tr>
<td>Utilities &amp; Communications</td>
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<td>344</td>
<td>305</td>
<td>533</td>
<td>871</td>
<td>734</td>
<td>975</td>
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</tr>
<tr>
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<td>206</td>
<td>154</td>
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<tr>
<td>Equipment</td>
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<td>164</td>
<td>60</td>
<td>4</td>
<td>127</td>
<td>497</td>
<td>424</td>
<td>911</td>
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<td><strong>Subtotal</strong></td>
<td>$3,382</td>
<td>$4,329</td>
<td>$1,752</td>
<td>$ 454</td>
<td>$4,982</td>
<td>$14,799</td>
<td>$14,200</td>
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<td><strong>Total</strong></td>
<td>$3,382</td>
<td>$4,329</td>
<td>$1,152</td>
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<td>$4,982</td>
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### STAFFING SCHEDULE
(In Full Time Equivalents)

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<table>
<thead>
<tr>
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<tbody>
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<td>1.00</td>
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## TABLE VI

**OPERATIONS & MAINTENANCE BY TYPE OF SERVICE**

* (Amounts in Thousands)

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<thead>
<tr>
<th></th>
<th>CTIO</th>
<th>KPNO</th>
<th>SUNSPOT</th>
<th>TUCSON</th>
<th>CENTRAL OFFICES</th>
<th>TOTAL FY-1989</th>
<th>TOTAL FY-1988</th>
<th>TOTAL FY-1987</th>
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<tbody>
<tr>
<td>Engineering &amp; Technical Services</td>
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<td>169</td>
<td>175</td>
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Subtotal O&M

|                         | 3,382 | $4,329 | $1,152 | $400 | $4,882 | $14,799 | $14,250 | $14,444 |

USAF & NASA Support

|                         | 6.600 | <54>  |        |      |        |        |      | <649> |

Total O&M-NSF Funds

|                         | 3,382 | $4,329 | $1,152 | $400 | $4,882 | $14,799 | $13,546 | $13,795 |

### STAFFING SCHEDULE

* (In Full Time Equivalents)

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Total

<p>|                         | 108.35 | 65.95 | 29.20  | 6.50  | 84.56 | 316.56  | 324.11 | 325.31 |</p>
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<td>TOTAL FY-1988</td>
<td>TOTAL FY-1987</td>
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