NATIONAL OPTICAL ASTRONOMY OBSERVATORIES

Cerro Tololo Inter-American Observatory
Kitt Peak National Observatory
National Solar Observatory

La Serena, Chile
Tucson, Arizona 85726
Sunspot, New Mexico 88349

ANNUAL REPORT
July 1990 – June 1991

January 28, 1992
# TABLE OF CONTENTS

## I. INTRODUCTION

## II. AURA BOARD

## III. SCIENTIFIC PROGRAM

### A. Cerro Tololo Inter-American Observatory (CTIO)

1. The Late-Time Luminosity Evolution of SN 1987A
2. The Most Distant Radio Galaxies
3. The Mystery of CN and CH Inhomogeneities in Globular Clusters

### B. Kitt Peak National Observatory (KPNO)

1. Resolved Images of High Redshift QSOs: A First Look
2. The Colors of Galaxy Clusters and the Nature of "Dark Matter"
3. A Giant Ionized Gas Cloud Associated with 3C 294: A View of Galaxy Formation?

### C. National Solar Observatory (NSO)

1. Near Infrared Magnetograph
2. High-Precision Polarimetry
3. Magnetic Fields of Active Regions
4. Progress in Adaptive Optics at NSO/SP
5. NSO/SP "Adaptive Mirror"
6. High Velocity Wind from a T Tauri Star
7. Magnetic Field Measurements

## IV. MAJOR PROJECTS

### A. Global Oscillation Network Group (GONG) Project

### B. 3.5-Meter Mirror Project

### C. WIYN Project

## V. GEMINI PROJECT

## VI. INSTRUMENTATION

### A. CTIO

1. Array Controllers
2. 4-m Prime Focus Corrector and Atmospheric Dispersion Correction; Large Format Prime Focus CCD
3. CCD TV Acquisition Cameras
4. 4-m Telescope Seeing Improvements
5. Other Projects
I. INTRODUCTION

This report covers the period 1 July 1990 – 30 June 1991.

The National Optical Astronomy Observatories (NOAO) consists of three major astronomical centers which are available for use by astronomers from the United States and around the world: Cerro Tololo Inter-American Observatory (CTIO), Kitt Peak National Observatory (KPNO), and the National Solar Observatory (NSO). CTIO, in northern Chile, at an elevation of 7,200 feet, is the national center for astronomy in the southern hemisphere for the United States. KPNO occupies a 6,900-foot-high site near Tucson, Arizona, and contains the largest single collection of optical telescopes in the world. NSO combines facilities at 9,200-foot-high Sacramento Peak, New Mexico with the giant McMath and Vacuum Tower telescopes at KPNO, providing an international center for studying the Sun.

II. AURA BOARD

The Association of Universities for Research in Astronomy, Inc. (AURA), operates the National Optical Astronomy Observatories under cooperative agreement with the National Science Foundation (NSF). AURA also operates the Space Telescope Science Institute (STScI) under contract with the National Aeronautics and Space Administration (NASA). AURA has a total of twenty-one member universities. Each member university appoints one individual to serve on the AURA Board, which also includes the President of the Corporation and twelve Directors-at-Large.

III. SCIENTIFIC PROGRAM

A. Cerro Tololo Inter-American Observatory (CTIO)

1. The Late-Time Luminosity Evolution of SN 1987A

No event in nature is more violent and powerful than the death of a massive star in the form of a type II supernova. For the star, it is the end of a comparatively brief but brilliant life, or at least the transition to a more exotic state. For astronomers, it provides not only spectacular fireworks, but a unique testing ground for theories of stellar evolution and explosion. SN 1987A, which appeared on 24 February 1987 in the Large Magellanic Cloud, our Galaxy’s closest neighbor, is the nearest and brightest supernova to be discovered since the invention of the telescope. It has provided the opportunity of a lifetime for astronomers to study a type II supernova in unprecedented detail. Visible only from the southern hemisphere, SN 1987A has been extensively followed by CTIO staff and visiting astronomers during the last four years, providing a truly unique observational record.

One of the most fundamental quantities in studying a supernova is the evolution of the so-called "bolometric" luminosity, which is simply the energy radiated over all wavelengths as a function of time. To calculate the bolometric luminosity at any instant, it is necessary to sum the radiation emitted, from gamma rays to the far infrared, excluding any source that is not directly part of the prompt energy release from the material in the supernova, such as an echo or stars lying along the line of sight. Observationally, the energy spectrum divides into two disjoint ranges, the "high-energy" flux due to the gamma-ray lines and X-ray continuum, which can only be observed from satellite or balloon instruments, and the ultraviolet-optical-infrared "uvoir" flux, which is mostly accessible to ground-based
telescopes. This division also has physical meaning. The high-energy component effectively represents the energy emitted directly in the radioactive decays of the newly synthesized nuclides, whereas the uvoir component is a measure of the thermalized energy derived from the same radioactive decays, or from other sources such as the initial shock wave produced by the explosion or a buried pulsar.

Using an extensive set of optical and infrared photometry, spectroscopy, and imaging observations obtained at CTIO, N.B. Suntzeff, M.M. Phillips, J.H. Elias, and A.R. Walker, along with D.L. DePoy (Ohio State U.), have followed the temporal evolution of the uvoir bolometric luminosity of SN 1987A through day 1442 since the explosion began. These data show that for the first two years, the dominant energy source for the supernova was the radioactive decay of approximately 0.069 solar masses of $^{56}$Ni, which was synthesized in the initial seconds of the explosion. The $^{56}$Ni, which has a half-life of only 6.1 days, quickly decayed to $^{56}$Co, which itself decayed with a much longer half-life of 77.1 days to the stable isotope $^{56}$Fe. By day 1000, however, Suntzeff and collaborators found that another source of energy besides the radioactive decay of $^{56}$Ni (and $^{56}$Co) was needed to explain the slow leveling off of the uvoir luminosity decline. The most likely explanations for this behavior are 1) the radioactive decay of $^{57}$Co to $^{57}$Fe (half-life of 271 days), 2) the energy of a buried pulsar, or 3) contamination due to an underlying light echo. Only the first alternative provides a good fit to the data at all times. The final $^{57}$Fe/$^{56}$Fe isotope ratio implied by the uvoir data is somewhat higher than the theoretical expectations, but Suntzeff and collaborators were able to show that the observed upper limits on the hard X-ray emission of the supernova are consistent with this value. Significantly, model fits, in which a constant energy source such as a pulsar is included, are clearly inferior to the pure radioactive decay models. Consequently, there is still no direct evidence that the explosion of SN 1987A left behind such an object.

2. The Most Distant Radio Galaxies

The physical study of galaxies at large look-back times is one of the most challenging and rapidly changing areas of astrophysics. Radio galaxies are currently unique in that they are the only objects in which star light can be observed over a look-back time comparable to the age of the universe. Over the past two years, P. McCarthy (Carnegie Inst. of Washington), W. van Breugel (Lawrence Livermore National Lab.), and V. Kapahi (Tata Inst. of Fundamental Research, India) have used the CTIO 4-m telescope to conduct a spectroscopic survey of intermediate flux density radio sources in the southern hemisphere. The sources were selected in a manner that optimizes the likelihood of reaching redshifts of 2 and larger, without introducing undue bias in radio properties. To date, McCarthy et al. have obtained redshifts and spectrophotometry of thirty-five radio galaxies, fifteen of which have redshifts greater than 2, making this one of the largest samples of galaxies at cosmologically-interesting distances.

Radio galaxies at large redshift have properties that are remarkably different from present-day massive elliptical galaxies. In particular, imaging observations have shown that many of the distant radio galaxies have a characteristic multi-modal structure composed of roughly linear chains of high surface brightness ultraviolet continuum clumps distributed on scales of 10 to 100 kpc. The independent discovery in 1987 by McCarthy et al. and Chambers et al. that these lumpy and elongated galaxies are closely aligned with the ejection axes of their radio sources has dramatically changed our thinking regarding the evolution of these massive galaxies. This "alignment effect" occurs nearly exclusively at redshifts greater than or equal to 1. The giant emission line nebulae also found to be associated with these galaxies are likewise strongly aligned with the radio source axes. This alignment extends to redshifts lower than the continuum alignment. The origin of these strong radio/optical correlations is unclear and has become the focus of a number of recent theoretical investigations. Models seeking to explain the alignments have invoked stimulated star formation, scattered light from an obscured quasar nucleus, and gravitational
lensing. However, recent high signal-to-noise spectroscopy of radio galaxies with \( z \sim 2 \), published in 1989 by Chambers and McCarthy, suggests that the ultraviolet light is dominated by massive stars, favoring models in which star formation is induced by radio sources.

While the origin of the strong starbursts observed in these objects is still unclear, multi-color photometry at the longest wavelengths available from the ground can be used to constrain the ages of the oldest stellar population. The galaxies show a wide range of rest-frame UV to rest-frame visible colors, which can be attributed to either a range of ages, and hence formation redshifts, or as starbursts of varying amplitudes superposed on a single generation old stellar population. Of particular interest are the reddest objects at high redshift. An example is the galaxy 0156-252 whose redshift of 2.02 was measured by McCarthy and collaborators with the CTIO 4-m telescope in 1989. A fit to the broad-spectral energy distribution of this object implies a redshift of formation of at least five, and perhaps as large as twenty, depending on the evolutionary model used. These very red objects are quite rare, yet vitally important, in that they currently provide some of the strongest constraints on the epoch of galaxy formation.

3. The Mystery of CN and CH Inhomogeneities in Globular Clusters

The chemical composition of the numerous globular clusters in our galaxy varies from cluster to cluster. It has long been known, with one exception, that individual stars within a given cluster are remarkably uniform in the abundance ratio between the heavier or metallic elements and hydrogen. In color-magnitude diagrams this uniformity explains the extreme narrowness of the giant branches. Early metallicity determinations based on the relative strengths of ultraviolet light, which can be significantly diminished by metallic absorption lines, and of blue light, confirmed that a very small metallicity spread is generally found within a given cluster.

In 1973, R. Zinn (Yale U.), observing with the KPNO 2.1-m telescope, found that six out of twenty stars observed in the cluster M92 showed abnormally weak CH \( \lambda 4300 \) molecular bands. In order to investigate this apparent chemical inhomogeneity, J.E. Hesser (then at CTIO), and F.D. Hartwick and R.D. McClure (Dominion Astrophys. Obs.), used the CTIO 1.5-m telescope in 1976 to measure the strengths of the CN \( \lambda 4215 \) band in several stars in various globular clusters. Narrow band-pass filters centered on \( \lambda 4215 \) Å and on a neighboring part of the continuum were used to measure photometrically the CN bands. Unexpected large differences were found among the stars in a given cluster. In follow up studies by Hesser and various collaborators, it was found that the distribution of CN band strengths could be bimodal in a given cluster. The bimodality was confirmed in 1979 by J. Norris and K.C. Freeman (Mt. Stromlo Obs.). In 1978, J.E. Hesser (then at Dominion Astrophys. Obs.) was able to obtain low resolution spectra of some eighty stars in the bright southern globular cluster 47 Tucanae with the CTIO 1.5-m telescope. He found CN strength differences in stars in the upper part of the main sequence as well as in the horizontal and giant branches.

This result was confirmed in 1983 by Hesser, in collaboration with R.A. Bell (U. of Maryland) and R.D. Cannon (Royal Obs., Edinburgh), with high resolution spectrograms obtained with the CTIO 4-m telescope. Furthermore, in 1989, observations with the same telescope by G.H. Smith (STScI), Hesser, and Bell showed that the CN \( \lambda 4215 \) and CH \( \lambda 4300 \) band strengths in 47 Tucanae were anti-correlated.

The elements C and N play a major role in the CNO thermonuclear cycle operating in the interior of a star. In the \( ^{12}\text{C} \) cycle, nuclei are converted to \( ^{13}\text{C} \), and eventually to \( ^{14}\text{N} \). The net effect is to increase the abundance of \( ^{14}\text{N} \) and to decrease the abundance ratio \( ^{12}\text{C}/^{13}\text{C} \) from a value close to 90 to about 3. Such a low \( ^{12}\text{C}/^{13}\text{C} \) ratio was found in 1987 by CTIO observers J.A. Brown and G. Wallerstein (U. of
Washington). In 1980, N.B. Suntzeff (then at U. of California, Santa Cruz), observing with the Lick Observatory 3-m and the KPNO 4-m telescopes, found no evidence for variation of the abundance ratio \((C+N)/H\), although C and N appeared to be anti-correlated. These results strongly suggested that CNO processed material was present in the outer layers of some stars and was the cause of the CN and CH inhomogeneities. Subsequently, the following questions arose: Was this material the result of deep mixing between the thermonuclear and outer layers of individual stars or had it been processed prior to the stars formation? Could mass-transfers in stellar encounters explain the observations?

The deep mixing possibility, is supported by findings from several investigators that the C abundances and the value of the \(^{12}\text{C}/^{13}\text{C}\) ratio decrease as a star evolves along the giant branch in a cluster's color magnitude diagram. Additional support for this possibility was obtained by C. Pilachowski (KPNO) with the KPNO 4-m telescope and by J.B. Brown, G. Wallerstein, and J.B. Oke (California Inst. of Tech.) with the Palomar 5-m and the CTIO 4-m telescope. These investigators found that individual stars in each of several clusters, whether CN-strong or not, had the same net C+N+O abundance, as expected in material that has undergone CNO processing within a given star.

There is evidence that other processes are at work as well. In 1981, P.L. Cotrell (U. of Texas) and G.S. Da Costa (Yale U.), observing with the CTIO 4-m telescope, found an enhancement of Na and Al abundances among CN-strong stars in two clusters. These enhancements are not expected to result from CNO processing. Recently, M.M. Briley (U. of Texas), J.E. Hesser, and R.A. Bell obtained spectra of ten main sequence stars in 47 Tucanae with the same telescope. Among these were stars appreciably fainter than previously observed. Surprisingly, these stars show the CN bimodality although, in theory, no deep mixing should occur in such unevolved stars. It is not clear whether primordial processes in the proto-cluster clouds explain these two results. Evidence suggesting that the environment of a star within a cluster may play a role, at least in part, is derived from observations that indicate there is a radial gradient in the nature of the CN bimodality in 47 Tucanae (J. Norris and K.C. Freeman at the Anglo Australian Telescope Observatory). Stellar encounters, that should be more frequent towards the cluster’s center and accompany mass exchange, can explain this result.

The considerable effort spent towards explaining the CN and CH inhomogeneities has produced strong evidence in favor of the role played by the CNO cycle and some evidence favoring the deep mixing hypothesis. Nevertheless, this may not be the only explanation. Further efforts may result in a better understanding of how the clusters were formed and of the mixing mechanism in stellar interiors.

B. Kitt Peak National Observatory (KPNO)

1. Resolved Images of High Redshift QSOs: A First Look

Soon after their discovery, quasi-stellar objects were so named because their optical images were unresolved and stellar in appearance. These objects have become familiar over the years, but in many ways they remain as enigmatic as ever. They form the class of the most distant objects in the Universe and produce the most energetic and explosive events ever seen. These two properties make an understanding of the nature of quasi-stellar objects essential to cosmology, general relativity, and high energy physics. Because these objects emit up to one hundred times the energy of all the stars in a normal galaxy from regions a millionth the size of a galaxy or less, some extremely powerful and very concentrated form of energy generation is necessary. The only viable candidate at the present time is the gravitational singularity, or black hole. The formation of a black hole of sufficient mass to power a QSO is thought to occur during the late stages of the evolution of a self gravitating system. Therefore, the appearance of
QSOs at high redshift early in the evolution of the universe may require extraordinary and rapid evolutionary paths for these objects. Until recently, the only spatially resolved features associated with QSOs were the regions of extended radio emission associated with a subset of these objects. These radio features were remarkably similar in nature to the less powerful radio emission arising from some elliptical galaxies. This similarity provided a tantalizing possible link between galaxies and QSOs, but their point-like optical appearance seemed to preclude QSOs from being a special form of galaxy.

This situation has now changed due largely to the remarkable increase in sensitivity provided by state of the art detectors used at the KPNO telescopes. Using the KPNO 4-m telescope and a UV-flooded 800 x 800 pixel CCD detector at the prime focus, T. Heckman and M. Lehnert (Johns Hopkins U.), W. van Breugel (Lawrence Livermore National Lab.), and G. Miley (Sterrewacht, Leiden) have obtained spatially resolved images of fifteen QSOs, all lying at redshifts greater than or equal to 2.0. The resolved images are all seen in Lyman-α emission, with typical size of 100 kpc and a typical luminosity of $10^{44}$ ergs/sec. All of these QSOs are associated with radio emission. The optical nebulae are usually elongated, with the axis of elongation being aligned with the radio emission, or asymmetric. In this regard, these objects are very similar to the population of high redshift radio galaxies that has recently been discovered. Photoionization arguments suggest that the radio emission arises from small dense clouds. The production and confinement of such clouds implies a gas cloud around the QSOs which contains up to $10^{12}$ solar masses of gas. In six of the QSOs, the UV continuum is also resolved, having diameters of 40 to 80 kpc. This UV emission could arise from starlight in a host galaxy or from scattered QSO light. Although the mechanism that gives rise to the QSO emission may be unique and still obscure, these observations strongly suggest that the underlying parent object may be a system of stars. This, in turn, provides very strong boundary conditions on models for the "central engine" in these objects, since they must evolve out of a gravitationally bound stellar system. Consequently, the high redshift problem described above becomes even more severe. It is not clear that conventional cosmological models will allow enough time for the formation of a galaxy, the evolution of a dense stellar core, and the final collapse to form the putative black hole.

2. The Colors of Galaxy Clusters and the Nature of "Dark Matter"

In 1933, F. Zwicky first pointed out a discrepancy between the velocities of galaxies in rich clusters and the total mass of stars in these systems. Assuming that these clusters have reached equilibrium, the velocity dispersions indicate much more mass than can be accounted for by conventional stellar populations in the member galaxies. The "Dark Matter" problem has grown from this first exposition into a major area of astronomical activity, with non-luminous material apparently existing in many places, always provided that the assumption of virial equilibrium is correct. In fact, the currently fashionable cosmological models require most of the mass in the universe to be invisible, since these models are based upon the assumption that just enough mass exists to gravitationally bind the universe. However, there is no direct observational evidence for this much matter. Current observational limits provide only a few tenths of the required mass. Although the desire persists in many quarters for this dark matter to be in the form of exotic, unobserved particles, much of it could be in the form of baryonic matter. If so, this material could be in the form of very low luminosity stars, which is a plausible outcome given the general steep slope of stellar mass functions in the low mass region.

An investigation of this possibility has been carried out by J. Uson (National Radio Astron. Obs.) and S. Boughn (Haverford College). Using the KPNO 1.3-m and 0.9-m telescopes, these astronomers have obtained single-aperture and CCD photometry on and near the centers of distant (0.14 < z < 0.20), rich Abell clusters. Four clusters (A910, A1413, A1763, and A2218) were measured in the B, V, R, J, and K...
bands. These bands were chosen because they would reveal the presence of a large population of very low
mass stars. For example, if the dark matter were in the form of the faintest known stars, it would produce
a K-band luminosity comparable to that of the visible galaxies but contribute essentially nothing in the
V-band. This would result in a clearly observable shift in the V-K color index from that seen in normal
galaxies. Uson and Boughn find no anomalous infrared emission from the galaxies in these clusters. In
fact, their observations show that no more than five percent of the dark matter can reside in objects of
mass greater than 0.1 solar mass. This interesting result does not imply that the dark matter must be non-
baryonic, but it does place constraints on the lower end of the mass function if the matter is baryonic and
condensed. For example, with a low mass cutoff of 0.004 solar masses (thought to be the minimum
collapse mass) and an upper limit of 0.75 solar masses, the power-law exponent of the differential mass
function must be greater than 2.4. In any case, it is clear that these new results place important constraints
on galaxy formation and evolution models that seek to incorporate the dark matter in condensed form.

3. A Giant Ionized Gas Cloud Associated with 3C 294: A View of Galaxy Formation?

3C 294 is a high redshift (z = 1.786) radio galaxy belonging to a class of objects that has received
considerable attention in recent years. These objects are steep spectrum double radio galaxies, all at large
redshift, which show a remarkable alignment of optical emission coincident with the axis of the radio
source. This optical emission is seen primarily in emission lines, but it is also present in the visible
continuum and in the infrared. The extent of the emission is comparable to that of the radio source
(10-100 kpc). Its origin is thought to be linked in some way with the ejection of the radio emitting plasma
from the active galactic nucleus. This morphology is not seen in comparable radio galaxies at low redshift,
suggesting that evolutionary processes must be playing a crucial role. The detailed nature of this process
is not yet clear. If the optical emission elongated parallel to the radio axis comes from starlight, then it
is possible that a burst of star formation has been triggered by the passage of the radio jet through the
circum-galactic medium. Since this is not seen in low redshift radio galaxies, it would imply that the gas
around high redshift galaxies may be extremely dense compared to that found in the present epoch. Even
if the light is not primarily from stars, the presence of emission lines implies the presence of large
amounts of gas enriched with heavy elements located very far from the normal stellar extent of the parent
galaxy. If such gas is present at early epochs, it could be associated with the galaxy formation process
itself.

This idea has received new impetus with the detection of a cloud of ionized gas in 3C 294 that may be
revealing the late stages of galaxy formation. Using the KPNO 4-m telescope, P. J. McCarthy (Carnegie
Observatories), H. Spinrad, W. van Bruegel, and M. Dickinson (U. of California, Berkeley), J. Liebert
(Steward Obs.), S. Djorgovski, (California Inst. of Tech.), and P. Eisenhardt (NASA Ames) have obtained
images of a giant region of Lyman-α emission 100 × 170 kiloparsecs in extent. Once again, the long axis
of the cloud is aligned with the radio source. The cloud is co-located with emission line regions in N, C,
and He, and it possesses a smooth velocity gradient of 1500 km/s together with very large line widths of
up to 2600 km/s. The size of this object is very large, and the mass of the gas is estimated to be about
10^9 solar masses. The kinetic energy of the ionized cloud alone lies in the range of 10^{37} to 10^{39} ergs, which
is an enormous amount of energy for an object perceived to be "passive." The origin of such a cloud is
clearly a question of interest, especially since it has no known low redshift counterpart. One tempting
possibility is that the cloud is a remnant of the protogalactic nebula and is currently falling into the young
galaxy that formed from it. The presence of emission lines indicates an episode of early star formation,
but this constraint on galaxy formation models has been known for some time. Further study of this
extreme example of high redshift Lyman-α emission is required as well as incorporation of the constraints
these observations provide into models of galaxy evolution.
C. National Solar Observatory (NSO)

1. Near Infrared Magnetograph

The NSO Near Infrared Magnetograph (NIM) is initiating a new field of study: the spatial organization of small-scale solar magnetic fields. It has been known for years that the photospheric magnetic field outside of sunspots characteristically occurs in the form of intense ($B \approx 10^3$ gauss) but very compact ($d < 10^3$ km) magnetic concentrations known as flux tubes. Visible-light observations of flux tubes provide indirect diagnostics that must be cautiously interpreted with the aid of models. Observationally, the essential difficulty is that the Zeeman splitting of spectral lines in the visible region is too weak to measure kilogauss magnetic fields directly.

Working at 1.56 μm, NIM exploits the $\lambda^2$-dependence of Zeeman splitting to measure $|B|$, the magnitude of the magnetic field vector (regardless of its orientation). NIM has produced the first true-field magnetic maps of solar plages. The observed field strength varies over at least the range 800-1700 gauss, compared to an uncertainty in the individual measurements of ± 7% (for $B > 800$ gauss). The true field strength is only loosely correlated with magnetic flux as measured by conventional solar magnetographs. The areal filling factor is often greater than 0.1 and extends up to 0.5. This is larger than typical indirect estimates based on visible-light data and may indicate that the spectrum of flux tube sizes is weighted toward higher values than are usually assumed in theoretical models. The individual Zeeman components are measurably broadened, reflecting a range of field strength within individual flux tubes or among tubes within the spatial resolution element.

NIM is available to visiting observers and constitutes a unique tool for the study of solar magnetic fields.
Figure 1: Magnetic field strength in a solar plage region: as it appears to a conventional magnetograph (left) and as it is measured by the Near Infrared Magnetograph (right). The NIM measures $|\mathbf{B}|$, the local magnitude of the magnetic field vector, regardless of its orientation. The conventional magnetograph is sensitive only to the line-of-sight component of $|\mathbf{B}|$ averaged over the angular resolution element. Because solar magnetic fields are concentrated into intense “flux tubes” a fraction of an arcsecond in diameter, the spatially averaged measurement provides no information about the true field strengths. The new results from NIM prove that these strong fields can be directly measured and show a significant spread in $|\mathbf{B}|$ with a coherent spatial pattern. The study of these “true-field” magnetograms and their relationship to flow fields should advance our understanding of magnetic fields in the photosphere.

2. High-Precision Polarimetry

High angular resolution studies of solar vector magnetic fields are extremely important in understanding magnetoconvective processes on the Sun, especially flare phenomena. The polarizing effect of large solar
telescopes has proven difficult to characterize with high accuracy, thus precluding high-precision polarimetry, at least at visible wavelengths. Laurence November (NSO/SP) has performed an analysis of the polarizing characteristics of the Vacuum Tower Telescope at Sacramento Peak, and confirmed the results by direct polarization measurements at the 1% accuracy level.

More precise polarimetry requires improved methods of calibration. To achieve this, November has carried out a generalized formulation for ellipsometry measurements, introducing two theorems: the congruency transform inverse and the similarity transform inverse, applicable to different calibration schemes for a general optical system. One of these involves simply the arbitrary rotation of a crystal sphere, a system confirmed in practice. Beyond this, a polarimeter design based on liquid-crystal modulators is being developed. This new polarimeter should permit unprecedented accuracy for a solar polarimeter with high angular resolution, 0.01%, so that observations will be limited only by the birefringent nonuniformity of the VTT window.

3. Magnetic Fields of Active Regions

Robert Howard has continued his studies of the magnetic fields of plages and sunspots. This work is aimed toward a better understanding of the surface structure and dynamics of active region magnetic fields and the connection of these fields to subsurface magnetic flux tubes. The overall goal is to provide additional constraints to models of the solar activity dynamo mechanism. In recent work, it has been demonstrated that there is good evidence in the case of plage fields, and to a lesser extent sunspot fields, for the resubmergence of at least some of the magnetic flux in the later stages of the evolution of a region. This result stems from analyses, both in the growing and decaying phases of regions, of the relative rotation rates of the leading and following portions of the regions and of the east-west inclinations of the magnetic field lines of the leading and following fields. From the same data, it is clear that the magnetic field in the growing stage of a region is in the form of a rising loop. Another study showed that growing plages are strongly inclined to lead the rotation, and growing sunspot groups are slightly inclined to trail the rotation. This remarkable difference in the characteristics of growing surface magnetic field structures has, to date, no explanation.

4. Progress in Adaptive Optics at NSO/SP

The Lockheed 19-segment adaptive mirror, operating on its test bed on the Sacramento Peak Vacuum Tower Telescope (VTT/SP), is proving to be worth the decade of development devoted to it by R. Smithson, R. Sharbaugh, S. Acton, and many others at Lockheed (LPARL). The recent modification to the system and software, by Acton (LPARL), has allowed automatic control, via a Microvax computer, of the offsets and gains of the 38-XY channels that steer the segments. Acton also implemented electrical adjustment of the offsets of all 57 servos that tilt and phase the segments. R. Dunn and L. Wilkins (NSO/SP) improved the optical system, aligned the quad cells in the Hartmann wavefront sensor to reduce the offsets supplied by the Microvax, and calibrated the input and output of the phase network that pistons the segments in and out to fit them to the continuous surface of the wavefront. The calibration is so accurate that the adaptive mirror itself can perform the correction of the overall tilt, a task that is usually left to the tilt/tip mirror inserted in the beam prior to the Adaptive Mirror. Videos taken by Dunn and the VTT observers on 18 July 1991, with a sunspot as a target, show spectacular real-time improvement of the images (Figure 2). In the middle of the day, when the disturbing layer is close to the pupil of the telescope and the "isoplanatic patch" is large, areas greater than 20 arcsec are considerably improved.
Real-time video solar observations with a segmented mirror are especially interesting to the adaptive optics (AO) community relative to single comparisons of corrected to uncorrected images of point sources. The video images show how the system performs dynamically and, perhaps more importantly, what is happening over the wide field of view visible in the pattern of granulation.

A 15-minute-long demonstration video has been assembled of sections of the July run. It includes a sequence that demonstrates the effectiveness of the phasing network. A group at Lockheed, led by A. Title, has enhanced the scientific value of this video by selecting the sharpest frames throughout the run, using correlation tracking to keep the frames in precise registration, "destretching" the entire scene, and applying some filtering. This data processing technique, developed by Lockheed as part of the SOUP and OSL effort, greatly improves the usefulness of ground-based observations.

Although the system has not yet been integrated into the VTT focal plane instrumentation, it is anticipated that it will be used in the near future for limited scientific observations in conjunction with the engineering runs to further refine the system. Spectrograph observations will benefit considerably from adaptive optics because of their long exposures, but will probably have to wait until the system is integrated into the NSO adaptive optical system.

Figure 2: Comparison of images of a sunspot as corrected by the Lockheed 19-segment mirror (from the observing run of 18 July 1991). Images from the corrected and uncorrected image video cameras were recorded simultaneously on a SVHS tape recorder. This "frame-grabbed" scene has not been processed by any enhancement techniques. The tic marks are spaced 1 arcsec apart. The telescope effective aperture is 35 cm. (LPARL Photo)
The Sac Peak Adaptive Mirror utilizes 61 piezoelectric actuators to distort a 267-mm diameter, 2.5-mm thick glass faceplate to fit the wavefront. The 6 μm extension of each actuator, made by Queensgate Instruments, is metered by a servo with a sensor that has a capacitor mounted on the end of a column of the low-expansion material Zerodur in the center of each actuator. The baseplate of the mirror assembly is a 100-mm thick, 344-mm diameter iron disk. Twelve spare actuators may be mounted around the outside of the central pattern so that their attachment mounting surfaces may be lapped together simultaneously with the 61 actuators in the center. A gimbal, which facilitates the lapping process, surrounds the baseplate. The glass mirror faceplate, which has steel buttons glued to it, is magnetically attracted to the actuators. The sequence of the assembly of these attachments is demonstrated on the lower row of actuators. A central, hardened pin passes through the magnet to bear on the steel button glued to the faceplate.
6. High Velocity Wind from a T Tauri Star

The compilation of Hα profile variability data acquired during the past four years for the T Tauri star SU Aurigae was completed during this year. The spectra were obtained by the resident nighttime observer at the McMath, Paul Avellar, as part of Mark Giampapa's synoptic program on pre-main sequence stars. In a parallel effort, similar data were acquired at Lick Observatory in a program conducted by Gibor Basri (U. of California, Berkeley). The Tucson and Berkeley groups have since combined data sets to produce an unprecedented catalog documenting the striking line-profile variability that can occur in a T Tauri star on a night-to-night basis. In collaboration with an undergraduate astronomy major at the University of Arizona, Eric DeFonso (who is now a first year graduate student in astronomy at the University of Texas, Austin), a movie was produced illustrating the variability seen in Hα. DeFonso also performed numerous measurements of line profile parameters for subsequent analysis.

A periodogram analysis of the data has led to a significant discovery, namely, the apparent modulation of the mass outflow from the star by rotation. In particular, the relative intensities of features in the blue wing of the Hα line spanning a range of velocities near $\approx 150 \text{ km s}^{-1}$ exhibit a modulation of approximately three days, which corresponds to the estimated rotation period of SU Aurigae. This important finding indicates that the relatively massive, high-velocity winds from SU Aurigae in particular, and perhaps T Tauri stars in general, can arise from localized regions on or near the stellar surface. Such localized regions of 'activity' are usually associated with complexes of magnetic fields in the Sun and the late-type stars. Hence, this interesting result implies that magnetic fields play an integral role in the structure and, perhaps, the origin of winds in pre-main sequence stars. This hypothesis is consistent with the Alfvén wave models of wind acceleration that have been proposed in the past for T Tauri stars. Further analysis of the data set is continuing along with the construction of preliminary models for the Hα line formation regions.

7. Magnetic Field Measurements

The Air Force-sponsored Solar Activity Modelling Initiative requires accurate knowledge of the magnetic and velocity fields observed at high spatial resolution. In order to convert the observed circular polarization in the Zeeman-affected spectral lines to longitudinal magnetic fields, various calibration methods have been tested and applied to the high spatial and spectral resolution observations obtained at the Vacuum Tower Telescope in conjunction with the NSO 20 mÅ filter. Observations were obtained on the active region AR 6615 located near the disc center on 4 May 1991. The seeing was estimated to be about 0.5 arcsec, or better, during the course of observations. The measurements consisted of sets of monochromatic images, in right and left circular polarization, acquired in the Fe I 5250.2 Å line (Landé g = 3) at thirteen equispaced spectral points, each separated by 20 mÅ, and completed in fifty seconds.

The various methods applied to calibrate the line-of-sight magnetic fields from the observed circular polarization are as follows: (a) the differences in the center-of-gravity of the right and left circular components for different spectral sampling; (b) conversion of circular polarization, at particular wavelengths, to magnetic fields using model-dependent numerical solutions to the equations of polarized radiative transfer; (c) the derivative method using the weak-field approximation. Further, retaining the high spatial resolution, the spectral resolution has also been degraded with a 120 mÅ bandpass filter to mimic the observations with a typical imaging magnetograph. The Air Force group has made comparisons of the various methods mentioned above. In addition, the spectral lines have also been simulated using numerical solutions to the equations of polarized radiative transfer for a grid of model atmospheres, magnetic field strengths, and their inclinations and azimuths.
The main result of this comparison is that the center-of-gravity method yields the best calibration of the line-of-sight magnetic field, with a maximum error of about 15% for highly inclined fields. It is concluded that a spectral sampling of 40 mÅ (or twice the FWHM of the Fabry-Perot interferometer) is quite sufficient to calibrate the magnetic field with reasonable accuracy.

IV. MAJOR PROJECTS

A. Global Oscillation Network Group (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—a technique known as 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 distributed data reduction and analysis system to facilitate the 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 GONG project passed a major milestone in FY 1991 when it announced the results of its site survey. The site survey activity began in 1985 and eventually included fifteen sites around the world. The final six sites destined to become the GONG network were announced last April at our annual meeting. They are Big Bear Solar Observatory, Mauna Loa Solar Observatory, Learmonth Solar Observatory, Udaipur Solar Observatory, Observatorio del Tiede, and Cerro Tololo Inter-American Observatory. The collection of site survey data was then terminated at all but the six selected sites and at Urumqi Astronomical Station, which still remains under consideration as a possible seventh site. Detailed Memoranda of Understanding are currently being negotiated between the project and the various host sites.

Work on the prototype Doppler analyzer continued throughout FY 1991. After several months of engineering upgrades, all of the primary elements of the Doppler analyzer system have been reinstalled at the prototype site and testing has resumed. This manifestation of the prototype instrument has several significant improvements over the system we were working with a year ago. In addition to a new interferometer and Lyot filter, a camera rotator is now in place, and a unique “tri-quad” solar tracking system has been installed and checked out. All of the electronics chassis and many of the cards in the system have been replaced by the production versions of the various command, control, and monitoring electronics.

The process of choosing and acquiring the final hardware for the GONG data reduction activity was begun in FY 1991, including an analysis of the requirements for the hardware. The first step involved a study of the time currently required to reduce the data, in addition to making estimates of the operation counts in both existing and planned software. Two hardware options are being considered: a highly centralized architecture based on minisupercomputers (e.g., Convex C-3), or alternatively, a highly distributed architecture based on workstations or equivalent servers (e.g., HP 750). Meetings were held with various manufacturers to configure and price out representative system architectures. A first cut at a design shows the centralized system to be about ten percent more expensive. This does not include increased installation and operations costs for the centralized system for air conditioning, electric power, and maintenance. It
also assumes extensive use of "previously owned" centralized hardware. The distributed network appears
to offer about a factor of two improvement in total bandwidth. After a more extensive review, GONG
plans to select an architecture and begin hardware procurement at the end of FY 1992.

GONG continues to hold its annual meeting. Significant adjustments have been made to allow the format
to evolve as the project moves into a new phase. Starting with the April 1991 meeting, the format became
less of a review of project developmental plans for the instrument and reduction software, and more
emphasis was placed on the scientific aspects of the project. The 1991 meeting was attended by a record
96 individuals from 14 countries and 37 institutions. The meeting included both oral and poster papers
coordinated by an organizing committee in response to submitted abstracts.

Over the first six years the project will have received about half of the funding proposed in the original
project plan for that period. Since major capital outlays from the budgets of two consecutive fully funded
years were proposed to build the stations, these progressive cuts have delayed the beginning of the
observations by at least four to five years. The project has revised its long range plan to attempt to deal
with the shortfall in capital funding. This has forced a departure from the originally proposed approach
that called for subcontracting the actual production of major systems for the instrument. Much of this work
will have to occur in-house. To further facilitate this approach, GONG has made a significant contribution
toward the purchase of a numerically controlled milling machine for the NOAO shops. This instrument
will permit cost-effective construction of production quantities of various precision-machined parts that
otherwise were to have been obtained through one or two major contracts. Further, it allows the work (and
capital outlay) to be spread out over the three years remaining in the construction phase of the project.
Observations are slated to begin in FY 1994.

B. 3.5-Meter Mirror Project

This year we completed polishing the 3.5-m mirror as a sphere. The accuracy of the spherical surface is
\(0.52 \lambda (330 \text{ nm})\) peak-to-valley and \(0.066 \lambda (42 \text{ nm})\) RMS \((\lambda = 6328 \text{ Å})\). The Strehl ratio calculated from
the point spread function is 0.55, and the image spot size is 0.033 arcsec FWHM.

Our optical testing capabilities continued to improve. The contrast of the interferograms was improved by
a vertical test shroud that reduces air turbulence and by improvement in the mirror figure. Several
improvements were made in the optical test software, including development of a program that calculates
a structure function from the phase map and extension of the set of Zemike terms available from 36 to
80.

After completion of polishing, the thermal sensors were removed, the mirror was thoroughly cleaned, and
66 Invar pads were bonded to the back surface as attachment points for the axial supports. Fabrication of
the mirror shipping container was completed by Autry Steel, and the mirror was successfully moved to
Kitt Peak for coating. During the first week of December 1990 the mirror was aluminized in the 4-m
coating chamber. The resulting coating is quite satisfactory.

The main weldment of the mirror cell arrived in October 1990. It was fabricated by L&F Industries and,
despite its size (14 feet across) and weight (7700 pounds), it is a precisely machined structure. Heavy steel
legs have been fabricated to support the mirror cell on the 4-m polishing machine table for testing.

The aluminized 3.5-m mirror was brought down from Kitt Peak in March 1991. Arrangements were made
to have a portable crane on hand to lift the shipping container into the building and remove the lid. This
plan worked well and helped keep the mirror out of the sun, avoiding the potential danger from concentrated sunlight.

In FY 1991, much effort has gone into preparing the components of the mirror cell assembly, which include the following: thermal sensors, blowers, air plenums, heat exchangers, and piping for the thermal control system; support mechanisms, hydraulic tubing, cabling, junction boxes, position sensors, and fluid level control units for the mirror support system; earthquake pads, position-defining linkages, and removable access panels.

A water chiller was designed that uses thermal electric coolers to control the temperature of the water supplied to the mirror cell. The design of the heat exchanger plates for this chiller was optimized empirically, and the plates were fabricated by an outside vendor.

The active optic control system was designed, fabricated, and installed. Thermal cycling tests of a prototype active support were conducted successfully. Assembly of the mirror cell, supports, cooling system, and control system took longer than had been forecast. By the end of June 1991 the mirror was mounted in its cell. The cell was installed on the polishing table and ready to start the Phase II test program. These tests will evaluate the performance of the mirror support, thermal control, and active optics systems.

**Division Support**

A Photometrics Star I CCD camera and a Mac 2 computer were purchased for curvature sensing experiments that work with the CCD to record images inside and outside of focus simultaneously. These experiments were aimed primarily at developing a test system that will be useful in the optics shop and could later be employed in the WIYN telescope to monitor telescope focus and image quality. This system was used to perform several tests during November 1991 on the SAO 1.5-m and 1.2-m telescopes on Mount Hopkins to (1) evaluate the aberrations of the telescopes, (2) determine whether they come from the primary or secondary mirrors, and (3) locate the position of Cassegrain focus having minimum spherical aberration. Personnel from Vandenberg Air Force Base and the China Lake Naval Weapons Center traveled to Arizona to witness these tests. They are trying to solve problems on their own telescopes, and the curvature sensing approach under development by NOAO may be the most promising test technique available. By the end of June 1991 similar tests had been conducted at the Kitt Peak 0.9-m, 1.3-m, 2.1-m, and 4-m telescopes. The results of these tests will be used to determine future telescope improvements.

**C. WIYN Project**

The University of Wisconsin, Indiana University, and Yale University joined together with NOAO to form the WIYN Consortium, Inc., incorporated in the State of Arizona in November 1990, following formal approval of the WIYN Agreement. The WIYN Project will make use of the 3.5-m mirror described in the preceding section. The WIYN universities are prepared to contribute a total of $8.5 M over the time period 1991-1994 for the construction of a new telescope on Kitt Peak. If Wisconsin, Indiana, Yale, and NOAO meet the obligations detailed in the WIYN agreement, then the observing time remaining after the allocation of maintenance and discretionary time would be apportioned in the following way: Wisconsin 26%, Indiana 17%, Yale 17%, and NOAO 40%.

During FY 1991, the project staff prepared detailed scientific and technical specifications for the WIYN telescope. The telescope will be, to a large degree, a copy of the ARC telescope on Sacramento Peak, but
with some modifications necessary to meet the requirements for a wide field and faster focal ratio appropriate for multi-object spectroscopy.

A contract was awarded to M3 Engineering in Tucson for architectural and engineering services to design the WIYN Telescope enclosure and control building. A preliminary design review was held in the spring of 1991, and a critical design review was planned for early FY 1992. Contractors were invited to pre-qualify to bid on construction of the enclosure and control building and four contractors were selected to bid. Site construction is expected to start in mid-FY 1992.

A design contract for the WIYN telescope mount was awarded to L&F Industries in California, the same company which built the ARC telescope. A preliminary design review was held in the summer of 1991, and the fabrication contract was awarded to L&F in August 1991. Detail design is underway and first metal is expected to be cut in the second quarter, FY 1992.

Preliminary design work was undertaken by the University of Wisconsin Controls Group, with detailed design of the controls system expected to begin in early FY 1992.

A 1.2-m diameter light-weighted blank for the secondary mirror has been ordered from Schott Glass Technology. Delivery is expected in March 1992. Vendors have been asked to submit bids to polish the blank to WIYN project specifications. Work continues on the other telescope subsystems, including the tertiary mirror and the instrument adapter.

V. GEMINI PROJECT

The 8-m telescope project was officially named Gemini in January 1991, by the international steering committee. The name stems from the plan to build two telescopes, one for the northern hemisphere and one for the southern hemisphere.

The NSF allocated funding for the project in FY 1991 in the amount of $4M. The funding was for initial staffing and design work on the project and for purchasing material for the primary mirror blank.

The United Kingdom Science and Engineering Research Council announced in December 1990, its decision to join the project. This was a key development in advancing the partnership. A draft Memorandum of Understanding was prepared during the year outlining the terms of the agreement and the plans for establishing the partnership, which would involve Canada, the U.K., and the U.S. In addition, Canada continued its planning efforts for astronomy and considered how the project would be integrated into the overall Canadian astronomy program.

International search for the Project Manager terminated in January 1991 with the selection of Lawrence K. Randall, Jr. Randall’s previous experience includes the positions of Engineering Manager for the KPNO and CTIO 4-m telescopes and Program Manager for the Faint Object Spectrograph for the Hubble Space Telescope. Randall began work in March 1991. At the close of FY 1991, he had selected three Engineering Managers: Henry Blair, for the Building and Enclosure Group; Keith Raybould, for the Telescope Mounting Group; and Larry Stepp, for the Optics Group. Patrick Osmer was named Interim Project Scientist by the international steering committee for the project.
The international partners agreed that the project should be located at NOAO Tucson headquarters during
the design and construction phase. NOAO provided space for the initial work on the project by purchasing
and installing modular buildings on the east roof of its main building.

A meeting was held in September 1990, at the Dominion Astrophysical Observatory in Victoria, B.C., to
discuss the scientific goals of the project, compare the engineering and costing efforts made to date in the
different countries, and assess how work packages for the project might be distributed among the different
countries. One outcome was the recommendation that a Science Advisory Committee be formed to develop
the Science Requirements for the project. Such a group was formed on a provisional basis and met, in
November in Oxford, to identify the main science goals of the project and begin the process of developing
the science requirements. The U.S. was represented by F. Gillett, R. Green, R. Schommer, and P. Osmer.
In addition to the scientific goals described in the national proposals, the meeting identified high
performance at infrared wavelengths, particularly outstanding image quality and low emissivity, as major
goals for the project.

The report of the Astronomy and Astrophysics Survey Committee was released in March 1991 and
included recommendations for an IR-optimized 8-m telescope for Mauna Kea and a southern 8-m optical
telescope. AURA directed NOAO to study the implications of the report and its relation to plans for the
Gemini telescopes. As a result, F. Gillett led an effort to define what IR-optimization would mean in
technical and design terms for the telescopes. This effort was integrated with the overall U.S. and Gemini
process to define the performance requirements for the telescopes. The process was underway by the end
of FY 1991 with plans to produce a draft of the Gemini science requirements for the October 1991
meeting of the Interim Gemini Board.

VI. INSTRUMENTATION

A. CTIO

During FY 1991, the CTIO staff continued its efforts to carry out a detailed site study for the location of
the southern 8-m telescope of the Gemini project, and for the 4-m telescopes planned by university
consortia. This study has concentrated on Cerro Pachón, the tallest mountain on the Tololo property. Cerro
Pachón was chosen as the primary site because its elevation (2,725 meters) is higher than Tololo, and
because previous site surveys showed that it is possibly a superior site. The north face is a vertical cliff
that faces into the prevailing north wind.

In order to make a direct comparison with the results of the NOAO site surveys of Mount Graham and
Mauna Kea, the same site testing equipment used in these surveys was installed on Cerro Pachón. This
equipment includes a 12-inch telescope used as a seeing monitor, echosondes to measure the lower level
atmospheric turbulence, 30-m towers equipped with anemometers, thermometers, and microthermal arrays,
and IR sky radiance monitors to determine sky emissivity and water vapor content. An analysis of the data
obtained since this study was initiated in July 1988 confirms the findings of the previous site surveys that
Pachón is an excellent site. However, in order to more fully compare the Cerro Pachón site with other
southern sites, the fabrication of two copies of the seeing monitors used for the Las Campanas Observatory
Magellan project site survey was undertaken in FY 1991. These telescopes, which are capable of
measuring the one dimensional image motion from 2 to 200 Hz, have been tested simultaneously with the
monitor used for the European Southern Observatory (ESO) Very Large Telescope site survey and have
been found to give identical results. The results from these new seeing monitors can be directly compared

17
to the Las Campanas and ESO surveys. The first of the seeing telescopes was installed on Cerro Pachón at the end of FY 1991, and plans call for the second to be installed on Tololo early in FY 1992.

1. Array Controllers

In late FY 1989, CTIO initiated a project to replace its aging array controllers. While these controllers have given excellent service over more than a decade, they are now showing their age, both in decreasing reliability and in lack of flexibility (e.g. the ability to read out multiple amplifiers on large-format detectors). A standard system architecture was defined jointly with KPNO. KPNO also participated in subsequent design and fabrication efforts. During FY 1991, the first prototype controller was completed and tested at the telescope. A modified prototype is to be tested in October 1991, with limited replication occurring shortly thereafter. A full production version will be produced later in FY 1992. The current version runs on the Tololo Sun computers, of which there are now one per telescope, including the Schmidt. A simple user interface permits the user to take CCD images and process them under IRAF; a more sophisticated interface will eventually be implemented, jointly with KPNO, as an NOAO standard.

2. 4-m Prime Focus Corrector and Atmospheric Dispersion Correction; Large Format Prime Focus CCD

A prerequisite for wide-field imaging at CTIO is the replacement of the older triplet correctors at the prime focus with a more modern design, which would produce better image quality over a wide field and would also provide better achromatic performance and good dispersion correction over the field. This project has been delayed substantially by difficulties encountered by the vendor in the fabrication and testing of the individual optical elements. However, almost all the elements are now completed and tested; mechanical and electrical design and construction of the mount are also largely complete, awaiting only delivery of the complete set of optical elements. The new corrector should be commissioned on the 4-m telescope for use for prime-focus photography and with Argus, the multi-fiber-feed spectrograph, in early 1992.

The new prime focus CCD unit is intended to permit use of large-format CCDs (up to 2 x 2 mosaics of 2048 x 2048 detectors with 15 μm pixels) with the new corrector. Work on this project will be completed soon after the new corrector is commissioned.

3. CCD TV Acquisition Cameras

This project, begun in FY 1988, was intended to produce sensitive TV acquisition cameras. A successful prototype was completed in 1989, and production work began later that same year. During the course of testing, it became clear that the camera could also be used for precise guiding. A number of modifications were made to enhance this capability and increase dynamic range.

Production has been carried out using a Chilean sub-contractor (DTS, ex-ENAER) to handle electronic fabrication and much of the board and assembly-level testing. This type of sub-contract work is likely to be used increasingly in the future for well-defined project tasks. Five of the nine cameras to be produced for CTIO have been completed and are in use on Tololo; the construction of the remaining four cameras for CTIO will take place at the end of 1991.

In addition to production of cameras for CTIO, copies of the cameras are being built, or will be built, for ESO, Las Campanas, and KPNO.
4. 4-m Telescope Seeing Improvements

In FY 1991, CTIO began a long-term program of improving image quality at the 4-m telescope. These efforts will extend over several years as CTIO attempts to achieve image quality at the telescope that is as close as possible to the intrinsic superb image quality of the site.

The first year of effort has concentrated on two areas: elimination of major heat sources in the 4-m dome and detailed analysis of the 4-m telescope optics. In the first area, activities that are not directly related to the operation of the telescope (e.g., library, electronics shop) have been moved out of the dome to other locations on the mountain; while resulting in some inconvenience to observers and mountain personnel, this move has substantially reduced heat generated within the dome. A project to cool the oil delivered to the horseshoe is nearing completion, and work to move the console room below the chilled floor level has also started; the present console room will be used only for set-ups, with a minimum of equipment turned on. Work is also beginning on design of a vent system to provide better airflow through the dome area by means of a system of large vents or doors in the dome. Water tunnel studies indicate that these vents will provide good passive airflow without the need for fans, which are expensive to operate.

Studies of the telescope optics have been carried out with the assistance of people from both ESO and KPNO. The purpose of these studies is fourfold: to optimize optical alignments, to identify deficiencies (if any) in the optical system that can be remedied by further project work, to identify areas where additional, active control would produce improvement, and to develop sufficient in-house expertise to maintain the resulting system at peak performance.

5. Other Projects

A number of improvements were made to the Rutgers Fabry Perot, mostly improved comparison lamp interface and a mechanical interface to the CTIO filter bolts. A variety of interference filters were purchased for use with this instrument and for direct imaging.

The design of the second generation imager has been simplified in order to reduce the resources required for completion and to permit its use on a greater number of the CTIO telescopes. As now designed, it will be usable on all CTIO imaging telescopes, including the Schmidt. An order has been placed for a 256 x 256 HgCdTe array (NICMOS III) from Rockwell, which will provide high-QE imaging in the 1-2.5 μm region, both broadband and narrowband. Mechanical design work will begin once the optical design is completed and the optics are ordered; the instrument electronics will be based on the new array controllers described above.

B. KPNO

In the period July 1990 through June 1991, significant progress was made at KPNO in the areas of instrumentation and in critical areas of operations on Kitt Peak. These activities are consistent with, and motivated by, the long range view of the role of KPNO in meeting the present and future needs of the U.S. astronomical community. Kitt Peak is a very good site, in terms of both seeing and sky brightness, and it is anticipated that its viability will persist well into the next century. In light of this, and in view of the coming presence of new telescopes and instrumentation on the mountain, a significant change in mountain management was begun with the hiring of a new manager for all operations on the site. Bruce Bohannan arrived in January 1991, to fill this new position, marking the beginning of many improvements in the operation of Kitt Peak, all of which are ultimately motivated by the goal of providing the most
effective possible acquisition of astronomical data. Changes involve improvements in procedures, in organization, and in the implementation of new programs such as seeing improvements and telescope upgrades. In addition, better processes for identifying critical maintenance areas are being developed, and some long standing and much needed maintenance items are finally being addressed.

In the area of instrumentation, activities are proceeding in an integrated manner that reflects a clear view of the role of KPNO in the future of astronomical research and in NOAO projects in particular. The development of the fiber-fed multi-object spectrometer will not only provide state of the art observing facilities at the KPNO 4-m telescope, but will also be integrated into the new 3.5-m WIYN telescope when it arrives on Kitt Peak. In addition to testing the 3.5-m mirror for this telescope and in assisting in the planning stages for the project, KPNO has begun to solicit community advice on the operational aspects of this facility. Detector development is also being carried out with future projects in mind, both in the evaluation of large format, high quantum efficiency infrared array detectors and in the development of CCD foundry runs and thinning technology. These activities will have a direct influence on instrumentation projects being developed for the NOAO proposed 8-m telescopes.

**Instrumentation**

Major accomplishments in FY 1991 in the optical and ultra-violet (O/UV) instrumentation program include the completion of the bench spectrograph and commissioning of the multi-fiber positioner to feed this instrument. In addition, continuing progress was made in the areas of CCD mosaic design and in CCD controllers and CCD development. In the area of IR instruments, major accomplishments were the completion and commissioning of the four-color IR camera (SQIID), the completion of the fast electronics effort, and the achievement of major advances on the cryogenic optical bench project. Each of these is briefly described below.

1. **Fiber-Fed Bench Spectrograph**

This instrument is now placed in a stabilized room specifically designed for this purpose. First light has been obtained with a red-optimized camera. Construction of a blue camera is underway. Construction of a cell to hold R-C gratings and automation of some critical components for increases in operational efficiency have been completed. A great deal of work was devoted to developing software to control the fiber positioners in an optimum and safe manner. Modifications to the x-y stage of the multi-fiber feed were made to overcome flexure problems present in the early design. Multi-object spectroscopy provides such enormous gains in throughput that it is anticipated that this instrument will be one of the most oversubscribed in the KPNO inventory.

2. **CCD Mosaic Imager**

The imager will be a mosaic of four 2048 x 2048 (or equivalent) CCDs in a common dewar. This project includes shutter and filter wheel interface to the 4-m prime focus, CCD controllers, and data handling computer hardware. Work in FY 1991 included preliminary design study, corrector design, conceptual design of the dewar, and design of readout electronics and power supplies. The project could be completed in two years. This long-term proposal represents the major new start for the group. CTIO is collaborating in this project, and the goal is to deploy a second imager in Chile.
3. Four Color Camera (SQUID)

This instrument has now been commissioned. Four 256 × 256 PtSi array detectors view simultaneously the same area of sky at wavelengths J, H, K, and L (1.2, 1.6, 2.2, and 3.5 μm). This large-field-of-view camera is used primarily in a "telescope raster" mode to build up images of a square degree or more in size. On-line data reduction is emphasized. The capability for simultaneous J, H, K imaging polarimetry has been designed already into SQUID; this function is enabled by the addition of a warm super-achromatic half-wave plate and a cooled analyzer. Closed cycle coolers are in use at the 1.3-m and remove the need for liquid cryogens in this and all subsequent instruments.

4. Cryogenic Optical Bench

The bench provides a versatile combination of broadband and narrowband filters, a polarimeter, an imaging Fabry-Perot, a coronagraph, and grisms in a single cryostat. The emphasis is on modular design: for example, the instrument will be commissioned with a low quantum efficiency PtSi detector. When a satisfactory large format high QE detector becomes available, the upgrade will necessitate no more than a straightforward plug-in module replacement. Much of the design work for the bench was done in 1991.

5. Infrared Developments for 8-m Telescopes

The KPNO Infrared Program is positioning itself to meet the requirements of the NOAO 8-m telescopes. Infrared astronomers are becoming increasingly aware of the potential of adaptive optics for image improvement. The 2 μm window is a particularly good place to work because the background from both atmospheric airglow and thermal emission is relatively low. The KPNO Infrared Program will enter this field with a development program that begins with relatively simple modifications to existing facilities and instruments. The first step will be adaptive correction to image motion through simple tilt correction, which should reduce the 2-3 μm image diameter by a factor of 2 in Kitt Peak median seeing. Work is proceeding at the 2.1-m telescope under contract with the Gemini project. A CCD camera will be used to provide a continuous position readout for the reference star, which may be any star in the field. The required brightness of the reference source will depend on atmospheric conditions, but will be sufficiently faint that the image stabilization option will be of wide applicability. The error signal will be used to close a fast guiding loop with the existing 2.1-m two-axis IR secondary.

This “fast guiding” endeavor is directly applicable to the design of an infrared optimized telescope. The necessary tests on optimized mirror coatings are now being initiated, and, by virtue of the cryogenic optical bench approach to instrument construction, the present generation of KPNO instruments can be regarded as prototypes for the 8-m telescopes.

6. PHOENIX

The experience gained at KPNO with CRSP, a low- and medium-resolution array spectrometer employing an SBRC 58 × 62 InSb array, amply demonstrates the power of IR arrays for spectroscopy. The optical design for the high resolution (R = 100,000) long-slit spectrometer PHOENIX is now complete, and work is proceeding on the mechanical design. This instrument will continue the strong tradition of high resolution IR spectroscopy begun at KPNO with the 4-m FTS and, because of the improvements in detector technology, will provide much greater sensitivities. For this reason, it will also be effective to use PHOENIX on the 1.3-m and 2.1-m telescopes.
C. NSO

1. Spectromagnetograph

The NASA/NSO Spectromagnetograph, developed jointly by the Goddard Southwest Solar Station and the National Solar Observatory, is now operating at the NSO/Kitt Peak Vacuum Telescope and is available for mission support and individual research by qualified scientists. This instrument will replace the two-slit detection used by the current 512-Channel Magnetograph. The spectromagnetograph records long-slit, spectrally resolved line profiles in left- and right-circularly polarized light and analyzes the data in cadence with spatial scanning of the solar image to produce digital maps with approximately one arcsec pixels of line-of-sight magnetic and velocity fields, continuum intensity, equivalent width, and line depth. During the past year, software to accomplish the real-time analysis was implemented. A final optical reimaging system was designed and fabricated, and it is being installed at the telescope. Data were obtained for numerous campaigns, rocket flights (e.g., GSFC’s SERTS 4 flight), and individual projects using prototype reimaging optics. Upgrades for the data control computer and video processor system have been purchased that will improve the speed, quality, quantity, and reliability of the real-time analysis.

2. He 10830 Å Video Filtergraph/Magnetograph

A new instrument for high spatial and temporal resolution imaging of solar active regions and flares in the 10830 Å line of He I is being developed under the Memorandum of Agreement between AURA and NASA/GSFC for use at the NSO/Kitt Peak Vacuum Telescope. The instrument will be able to run simultaneously with the spectromagnetograph. This line provides a unique view of the solar chromosphere and corona since the emission is produced in the high chromosphere but also responds to EUV coronal radiation incident from above. The instrument is based on a five-element Lyot filter to provide differential dual bandpass response and polarization modulation. Preliminary design and purchase of key optical elements were completed during the past year.

3. Near-Infrared Magnetograph

The Near-Infrared Magnetograph measures true magnetic field strengths in the deep solar photosphere using the McMath telescope, the vertical spectrograph, and the Zeeman-sensitive line Fe 15649 Å. The design of the Near-Infrared Magnetograph consists of three main subsystems, an infrared imager run in fast framing mode (currently the NOAO 68 x 52 InSb array detector), a liquid crystal polarization modulator, and a raster-scanning solar limb guiding system. Data taken with a prototype system in January 1990 have been analyzed and submitted for publication. In FY 1991, the bread-boarded instrument achieved its primary operational goal, a two-dimensional true-field magnetic map of the Sun. In early FY 1991, an Amber Electronics 128 x 128 InSb array detector system was purchased for use with NIM. Work has progressed steadily throughout FY 1991 on the control and I/O software required to operate the Amber system. The first use of the Amber with NIM is expected in early FY 1992.

4. High-l Helioseismometer

The joint NASA/GSFC, Bartol, and NSO High-l Helioseismometer allows observations of high-l (short wavelength) acoustic p and f modes to be made regularly at the NSO/Kitt Peak Vacuum telescope. The instrument design employs a versatile CCD image processing system coupled with a 1024 x 1024 CCD which records a full disk image of the Sun through a K-line interference filter. The observations will be performed approximately three days per month after the normal synoptic program at the NSO/Kitt Peak.
Vacuum Telescope. In early FY 1991, the instrument was taken to the South Pole for the austral summer observing season. Upon its return from Antarctica, the system was installed in a temporary fashion at the NSO/KP Vacuum Telescope. It is anticipated that the final mounting system will be installed in early FY 1992.

5. Stellar K-line Filter

Present techniques for measuring stellar rotation and activity cycles are restricted to observing one star at a time, a sequential procedure that is both slow and laborious. With the Stellar K-line Filter, many stars will be observed simultaneously in open clusters. Studies of open clusters have proven crucial in the verification and extension of the theory of stellar structure and evolution. Development of a temperature stabilized, tunable, narrow-band Ca II K-line filter is well underway. The filter is designed to have sufficient field of view to image an area several arcmin in extent. The filter, which was released for scientific tests in FY 1991, will be mounted in front of a UV-enhanced 800 x 800 CCD, and observations will be made at the McMath telescope. During preliminary testing a serious flaw in two of the optical elements was discovered. Further work has been put on hold, subject to the resolution of this design problem.

6. Solar-Stellar Cross Dispersion

The Reticon detector at the McMath stellar spectrograph was replaced in 1987 with a UV-enhanced 800 x 800 CCD. Although the speed gains (2 magnitudes) with the CCD have been remarkable, this detector is physically smaller than the retired Reticon and permits only half the former spectral length to be covered in an average exposure. Cross-dispersing the echelle grating will offset this disadvantage by placing four to five orders in a well separated format onto the CCD. The optical design must take into account the anticipated upgrade to a 1024 x 3072 Ford Aerospace CCD. This detector upgrade is tentatively planned for early FY 1993.

7. McMath 4-m Upgrade Study

A 4-m, all-reflecting solar telescope would foster new science in the infrared between 1 μm and 20 μm. At 12 μm, where seeing is significantly better than in the visible, a diffraction limit of 0.75 arcsec would ensure the direct measurement of non-sunspot magnetic fields in the high photosphere. Asteroseismology would become feasible for solar-type stars as faint as V = 7. The telescope superstructure would remain unchanged and most instruments would need only slight modification. Internal image quality would be preserved by the use of liquid-cooled, actively-supported, aluminum-based mirrors. The first step, executed in FY 1991, was to conduct an engineering study to determine, in detail, the technical feasibility of the proposed project and to better understand the costs involved. The engineering report is due in early FY 1992.

8. Adaptive Optics Systems

The Lockheed Adaptive Optics (AO) System has been developed by Scott Acton of Lockheed to allow substantial automatic control. Further improvements by Richard Dunn and Larry Wilkins of NSO/SP greatly improved the stability of the system to the extent that an extended observing sequence has been achieved with it. The video movie obtained during the observing run clearly demonstrates proper phasing of the AO sub-aperture mirrors. While this system is not optimized, the quality of image improvement points to the substantial resolution gain possible for ground-based solar observations with the use of
advanced adaptive optics systems. The development of the digitally-based NSO/SP AO system has continued. The large mirror system and actuators have been assembled and vacuum tested, while work has continued on achieving adequate flatness of the thin mirror surface. The digital reconstructor has been designed and is now under development (external contract). Other aspects of the system, such as the wavefront sensor, have undergone further development. In addition and as an ongoing program, the whole optical configuration of the VTT instrumentation has been modified to incorporate an AO system as a standard part of the instrumentation. This work has also involved the development of a horizontal spectrograph and other significant modifications to the overall system.

9. Correlation Tracker

This project has been completed. In a joint program with Kiepenheuer Institut für Sonnenphysik (KIS), two Correlation Trackers have been constructed, one now in regular use at NSO/SP, the other at KIS. More advanced designs are under review for an eventual Mk II version that would have more universal applications while being more supportable and simpler in design concepts and hardware.

10. One-Shot Coronagraph Upgrade

This program has involved incorporation of a CCD imaging and programmable observing sequence capability, while retaining the option of the original high-resolution film recording method. The required opto-mechanical system has been completed, while the CCD array and associated electronics and computer system, have been implemented to the point of imaging tests.

11. Perkin-Elmer Computer System Replacement at NSO/SP

This is part of a major program to update the hardware and software computer systems of the Vacuum Tower Telescope (VTT) Facility and the Evans Solar Facility (ESF). These systems will then be a model for the development of the Hilltop Observing Facility. For the VTT and ESF, hardware has been purchased and substantial work completed on data acquisition software and generic instrument modules.

12. Other Projects at NSO/SP

In addition to the above projects, other instrumentation development has been achieved, primarily through USAF funding. Principal projects only are mentioned here. The Mk II version of the White-Light-Flare telescope has been completed and tested and will soon be mounted on the Hilltop Spar. The Vector Magnetograph (Applied Physics Lab., Johns Hopkins University), mounted in the Hilltop Facility, has been improved in its reliability through optical, mechanical and electronic refinements, as part of a prototyping phase, to achieve accurate magnetic field observations. This work continues. The narrow-band (= 20 mÅ at 5000 Å) Fabry-Perot filter has been incorporated in the VTT Facility. Following thorough testing and calibrating, it is now available for general use. The major program of the development of reflecting coronagraphs has continued with the modification of the second prototype (MAC II), which has a 15-cm aperture superpolished objective mirror. A new secondary optical system (including a special metal annular field mirror) produced at Institut d'Astrophysique de Paris, was incorporated into MAC II, while the objective mirror mount was modified to allow ready inspection and cleaning of the mirror. Tests are continuing of the overall system. An advanced optical design for MAC III (55-cm aperture) has been completed that is capable of producing high angular resolution over an extended field.
VII. CENTRAL COMPUTER SERVICES

Tucson computing: A VAX 4000-200 was installed as replacement for the soon-to-be-retired VAX 8600. Time-shared Sun systems Tucana and Orion were upgraded from 3/160 and 4/280, respectively, to Sparcstation 2 systems. The shared Sun 4/470, designated Ursa, will replace the 8600 as our most powerful computer system. In the next few months Ursa will be upgraded to a 4 processor CPU with 128 Mb of memory. The number of systems in the Scientists Workstation Network was increased from 22 to 30, and a number of X-window terminals were installed, thus bringing modern desktop computing to most of the scientific staff. These changes continue our long-term plan to phase out support for VMS, provide a networked combination of powerful shared and personal computer systems for the scientific and technical staff, and significantly reduce our utility and maintenance costs.

A data line, T1 capacity (1.5 Mb/sec) leased from AT&T, bringing an Internet connection to Kitt Peak, was enthusiastically received by staff and visitors alike, but will have to be throttled back to lower bandwidth owing to very large lease cost increases.

Following several years of planning, the aging and expensive Dicommed image recorder was replaced with a Solitaire8, which accommodates 35, 70 mm roll film and 3 x 4 inch sheet film and polaroid module. This recorder offers approximately double the resolution of the predecessor and will operate with far less manual intervention. Convenient color imaging will be among the many new capabilities available with the Solitaire image recorder.

IRAF: Release 2.10, the first major release of IRAF in more than a year, is in beta testing at this writing for release in 1992. Many applications software additions are included for image processing, digital photometry, one- and two-dimensional and multi-object spectroscopy. System improvements include implementation of the world coordinate system for spectroscopy and plotting. New magtape support is provided with a table-driven interface, which accommodates all modern cassette and cartridge tape units.

A major effort during the year was the further development of the IRAF Control Environment (ICE), now in use at all KPNO telescopes, which allows users to control telescope and data acquisition from an IRAF window. The first version of ICE was implemented by S. Schaller (Steward Observatory) and subsequently imported to NOAO and considerably modified. As IRAF is widely used in the astronomy community, visitors find that ICE offers a familiar environment common to all telescopes and instruments as well as data reduction. User response has been very positive.

During FY 1991 considerable attention was given to planning for the international Astronomical Software and Data Analysis Systems conference, scheduled for November 1991, to be jointly hosted by NOAO, STSCI and SAO. More than 300 astronomers from 20 countries are registered to attend.

In the period 1 July 1990 through 30 June 1991, a total of 218 visiting scientists used the VAX 750s, VAX 8600, and workstation computing facilities at NOAO Tucson.
VIII. PERSONNEL

A. CTIO Scientific Staff Changes

Darren DePoy, Post-doctoral Research Associate, was offered a position of Assistant Professor of Astronomy at Ohio State University and left CTIO on 14 September 1990.

Andrew McWilliam, Post-doctoral Research Associate, left CTIO on 10 August 1990 to take up a position of Assistant Professor of Astronomy at New Mexico State University, Las Cruces.

Mark Phillips, Astronomer/Tenure, was appointed CTIO Assistant Director on 1 October 1990.

Robert Schommer was hired at the position of Associate Astronomer and started working at CTIO on 1 September 1990.

Nick Suntzeff, Associate Astronomer, was granted tenure on 25 January 1991.

Donald Temdrup, Assistant Scientist, left CTIO on 9 August 1990 to accept an Assistant Professorship at Ohio State University.

Robert Williams, CTIO Director/NOAO Associate Director, began an eleven month sabbatical on 16 May 1991.

Gerard Williger, Post-doctoral Research Associate, started at CTIO on 20 February 1991

B. KPNO Scientific Staff Changes

Bruce Bohannnan was hired at the position of Scientist and started working at KPNO on 2 January 1991.

Béatrice Müller (European Space Operations Center, Germany) was appointed to the position of Post-doctoral Research Associate on 9 August 1990.

David Silva (U. of Michigan) was appointed to the position of Post-doctoral Research Associate on 14 November 1990.

C. NSO Scientific Staff Changes

Craig Gullixon was hired as a Senior Associate in Research at NSO/Sacramento Peak and started on 25 February 1991.

Frank Hill was reclassification from Associate Astronomer to Scientist at NSO/Tucson on 1 January 1991.

Deborah Haber, Post-doctoral Research Associate, left NSO on 24 August 1990 to take up a teaching position in the Physics Department at Colorado College.

Greg Kopp, Post-doctoral Research Associate, started working at NSO/Tucson on 1 October 1990.
IX. DIRECTOR’S OFFICE

The current management structure for NOAO consists of the following employees: Sidney Wolff, NOAO Director; Pat Osmer, Deputy Director for NOAO; Dave De Young, Associate Director of NOAO for KPNO; John Leibacher, NSO Director/NOAO Associate Director; Robert Williams, CTIO Director/NOAO Associate Director; Mark Phillips, CTIO Assistant Director; Yvette Estok, Assistant to the NOAO Director; Robert Barnes, Assistant to the KPNO Director; Glen Blevins, Controller/Manager, Central Administrative Services; Larry Daggert, Manager, Engineering and Technical Services; John Dunlop, Manager, Central Facilities Operations; Karie Meyers, Public Information Officer; Steve Ridgway, Manager, Central Computer Services; and Ray Smartt, Deputy Director for NSO/Sacramento Peak.

The Director and her staff are responsible for the overall operation of NOAO. The Director is responsible for providing scientific leadership for NOAO, determining priorities, budget planning, and allocation of resources. The Director represents NOAO, and in particular, the three scientific divisions (CTIO, KPNO, and NSO) to AURA, Inc., the National Science Foundation, and to the scientific community.
APPENDIX A

National Optical Astronomy Observatories
July 1990 to June 1991 Technical Reports


Ming, L. 1990, SPIE, 1236, p.334, "Removable Atmosphere Dispersion Corrector for 8-M Telescope Design"

Osmer, P.S. 1990, SPIE, 1236, p.18, "The NOAO 8-M Telescopes Project"

Pearson, E.T. 1990, SPIE, 1236, p.628, "Hartmann Test Data Reduction"


Roddier, F., Graves, J.E., Limburg, E. 1990, SPIE, 1236, p.474, "Seeing Monitor Based On Wavefront Curvature Sensing"


Roddier, N. 1990, SPIE, 1237, p.668, "Atmospheric Wavefront Simulation and Zernike Polynomials"


Stepp, L. 1990, SPIE, 1236, p.615, "3.5M Mirror Project at NOAO"

APPENDIX B

Cerro Tololo Inter-American Observatory
July 1990 to June 1991 Publications List

During the period 1 July 1990 through 30 June 1991, 217 separate observing programs involving 332 scientists were carried out at CTIO. In the same time period, 268 papers were published based on the use of Cerro Tololo facilities.


Quintana, H., Ramirez, A. 1990, AJ, 100, p.1424, "Galaxy Velocities and Substructures in Southern Clusters: A496 and Sersic 40/6, Examples of Dynamical Cusps"


Reed, B.C. 1990, AJ, 100, p.737, "UBV Photometry of OB and Field Stars At $\ell = 250$"


Sharp, N.A., DePoy, D.L. 1990, ASP Conference 14, ed. R. Elston (ASP), p.67, "0.4 to 2.2μ Imaging of the Nucleus of the Hot-Spot Galaxy NGC 2903"


Stetson, P.B. 1991, ASP Conference 13, ed. K. Janes (ASP), p.88, "On Deriving Globular-Cluster Luminosity Functions from CCD Observations, with a Particular Application to the Main-Sequence Turnoff/Subgiant Branch in Metal-Poor Clusters"


Thompson, D.J., Djorgovskv, S. 1990, PASP, 102, p.959, "Spectroscopy of Quasar Candidates from the University of Michigan Low-Dispersion Survey"

Thompson, D.J., Djorgovski, S., De Carvalho, R. 1990, PASP, 102, p.1235, "Spectroscopy of Radio Sources from the Parkes 2700 MHz Survey"


APPENDIX C

Kitt Peak National Observatory
July 1990 to June 1991 Publications List

In the period 1 July 1990 through 30 June 1991, a total of 523 visiting scientists used the telescopes on Kitt Peak. A total of 128 visiting scientists used the KPNO data reduction facilities. A total of 334 publications were written by visitors and staff.


Christou, J.C. 1990, SPIE, 1237, p. 424, "Application of a Deconvolution Technique to Enforce a Priori Object Constraints to 2-D IR Speckle Data"


Fowler, A.M., Gatley, I., Merrill, K.M. 1990, SPIE, 1341, p. 52, "A 256 × 256 PtSi Hybrid Array for Astronomy Applications"


Ridgway, S.T., Christou, J.C., Probst, R.G. 1990, SPIE, 1237, p. 492, "Experience and Further Developments with the NOAO Infrared Speckle Camera"


Stetson, P.B. 1991, ASP Conference 13, ed. K. Janes (ASP), p. 88, "On Deriving Globular-Cluster Luminosity Functions From CCD Observations, with a Particular Application to the Main-Sequence Turnoff/Subgiant Branch in Metal-Poor Clusters"


17


APPENDIX D

National Solar Observatory
July 1990 to June 1991 Publications List

During the period 1 July 1990 through 30 June 1991, a total of 123 visiting scientists used the telescopes on NSO/Kitt Peak and NSO/Sacramento Peak. A total of 154 publications were written by visitors and staff.


Altrock, R.C. 1990, NASA CP 3086, ed. K.H. Schatten, A. Arking (Goddard Space Flight Center), p.287, "The Variation of Solar Fe XIV and Fe X Flux Over 1.5 Solar Activity Cycles"


Dunn, R.B., Darvann, T.A. 1990, Turbulence Power Spectral Density, "Using the Sun to Study the Earth's Atmosphere"

Dunn, R.B. 1991, SPIE, 1271, p.216, "NSO/SP Adaptive Optics Program"


Gaizauskas, V., Harvey, K.L. 1991, Flares 22 Workshop, ed. B. Schmieder, E. Priest, p.25, "Collisions Between Nested Sunspots: A Pathway to Flares"


Hill, F., Leibacher, J.W. 1991, Adv. Space Res. 11, 4, p.149, "Ground-Based Helioseismology Networks"


Koutchmy, S., et al. 1990, SPIE, 1235, p.849, "Real-Time Image Processing and Data Handling for Ground-Based and Spaceborne Coronal Observations"

Koutchmy, S., Zirker, J.B., Darvann, T.A. 1990, IAU Colloquium 117, ed. E. Tandberg-Hanssen, V. Ruzdjak (Springer-Verlag), "Distribution of Velocities in the Pre-Eruptive Phase of a Quiescent Prominence"

Koutchmy, O. 1991, Flares 22 Workshop, ed. B. Schmieder, E. Priest, p.103, "The Magnetic Field Configuration and Motions Over Regions with Impulsive Events and Prominence-Thread-Feet"


Livingston, W.C., Talent, D. 1990, S&T, 80, p.319, "Stalking Geosats with a Camera"


Livingston, W.C. 1991, J. of Climate Change, 18, p.121, "Energy Input to the Earth"

Livingston, W.C. 1991, IAU Colloquium 130, ed. I. Tuominen, p.246, "Convective Signature of the Solar Cycle from FTS Sun-as-a-Star Line Asymmetry Changes"


Malathy Devi, V., et al. 1990, J. Molec. Spectrosc., 143, p.381, "Line Positions and Intensities for the γ2 + 3γ3 Band of 16O3 around 2.7 μm"


Muller, R., et al. 1990, Publications of Debrecen Heliophysical Observatory, 7, p.150, "Formation of Network Bright Points by Granule Compression"


Rust, D.M., O'Byrne, J.W. 1990, SPIE, 1166, "A Low Polarization Solar Vector Magnetograph"


Sasada, H., Amano, T. 1991, J. Chem. Phys., 94, p.2401, "A New Triplet Band System of C\textsubscript{3}: The \( \tilde{b}^3\Pi_g \) - \( \tilde{a}^3\Pi_g \) Transition"


Strassmeier, K.G. 1990, Active Close Binaries, NATO ASI Proceedings, ed. C. Ibanoglu, I. Yavuz (Kluwer), "Synoptic Doppler Imaging and Photometry of Spotted Stars"


Willson, R.F. 1991, Flares 22 Workshop, Dynamics of Solar Flares, ed. B. Schmieder, E. Priest, p.155, "VLA Studies of Large-Scale Coronal Loops"


