Carnegie Observatories

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This report covers research done by Carnegie Observatories predoctoral, postdoctoral, and scientific staff during the period from July 1, 1996 to June 30, 1997.

1. PERSONNEL

Staff Members:

A. Oemler, Jr. (Director), H. Babcock (Director Emeritus), A. Dressler, W. Freedman, P. McCarthy, E. Persson, G. Preston, A. Sandage, L. Searle (Director Emeritus), S. Shectman, I. Thompson, R. Weymann

Las Campanas Research Staff:

M. Roth (Director, Las Campanas Observatory), P. Knezek, W. Krzeminski, W. Kunkel

Postdoctoral Fellows:

J. Dalcanton, M. Giavalisco, L. Lubin, J. Mulchaey, S. Trager

Postdoctoral Associates:

R. Phelps, C. Gallart, A. McWilliam, B. Rush, L. Storrie-Lombardi

Predoctoral Fellows:

R. Bernstein, Y. Hashimoto

Instrumentation Scientists:

D. Murphy

Supporting Staff:

Pasadena (31 persons), Las Campanas (38 persons)

2. RESEARCH PROGRAMS

2.1 Stars and Star Clusters

Preston has found that the color temperature, gravity, low metallicity, and carbon deficiency of HD 195636 indicate that this star is in an evolutionary state near the transition between horizontal branch and asymptotic giant branch. The projected equatorial rotational velocity of HD 195636 is 25 kms^{-1}, a value at least 2.5 times greater than expected if known blue horizontal branch axial rotators in globular clusters conserve angular momentum during horizontal branch evolution. Therefore, it seems probable that a transfer of angular momentum from core to envelope occurred during horizontal branch evolution.

Preston has completed the echelle observing program to detect spectroscopic binaries among 62 of the brighter blue-metal-poor stars. Observations in 1997 removed most of the period ambiguities introduced by annual observing sessions in prior years. The proportion of binaries with periods less than 2000 days is abnormally high and the mass functions are atypically small compared to F-type and G-type dwarf binaries in the solar neighborhood.

McWilliam, Preston, Shectman, and Thompson have begun a new search at Las Campanas Observatory for extremely metal-poor giants in the inner Galactic halo. A principal goal of the search is the identification of a large sample of extremely metal-poor stars for subsequent spectroscopic investigation at the large telescopes coming into operation in the Southern Hemisphere. A CaII K line index has been defined as the ratio of fluxes through narrow (FWHM = 20 Å) and wide (FWHM = 200 Å) interference filters centered on the CaII K line. The filters are used with the new du Pont Reimaging Camera designed by Weymann. Concurrent UBV CCD photometry at the 1.0m Swope Telescope provides the temperature and reddening estimates necessary to derive abundances from the K-line index. Some 40 fields (0.14 sq deg/field) in the strip $-2°<l<+2°$, $-30°<b<-10°$ were observed in 1997. Calibration of the K-line index by observations of numerous metal-poor red giants and several globular clusters indicate that the index remains sensitive to abundance at [Fe/H] = -4. From consideration of chemical evolution models, star densities in the inner halo, and the anticipated survey rate of 10 square degrees per year, the expectation is to discover between 1 and 10 red giants with [Fe/H] $<$ -4 and between 10 and 100 red giants with [Fe/H] $<$ -3 per year down to $M_v = +2$ in the inner halo.

Persson, Murphy, Roth, and Krzeminski, together with Rieke and Green (Steward Observatory) and Elias (NOAO) completed the infrared standard star project. The main goal of this project was to provide a set of standard stars for use in the near-infrared, out to 2.5 microns, by the NICMOS camera on the Hubble Space Telescope, the recently commissioned 2mass all-sky infrared survey, and by present and future large ground-based telescopes. A secondary goal was to determine the color transformations of their photometric system by measuring precise colors for a set of stars spread over a rather large color range. These data can then be compared to existing and future data obtained with different filters and instruments at different sites, thus allowing any researcher to either check or transform their data to this system.

All ground-based data were obtained with infrared cameras based on NICMOS infrared detectors manufactured by the Rockwell International Science Center. The observations were made on the 1m and 1.5m telescopes at Las Campanas and Palomar Observatories, respectively. The first phase of the project was to step directly from the Elias *et al.* (1982) 7th magnitude standards to a set of 17 new ones, all around 11th magnitude at K. Each of these was measured typically 10, but as many as 17 times in the J, H, K, and Kshort passbands. Reduction of the data on these 17 showed that typical one-sigma measurement uncertainties are around 0.005 magnitudes in all four passbands. Next, these 17 stars were used as ''standards'' to expand the list to a total of 65 new standard stars. Several stars in the latter group have been measured more than 20 times. In collaboration with Elias, a set of red stars spread over a J-K color range of more than six magnitudes was selected. No less than four measurements have been made of each of 20 stars. The standard star magnitudes and finding charts are available from S. E. Persson at persson@ociw.edu.

Sandage continued his study of the sensitivity of the ab-

solute magnitude of classical Cepheids on metallicity. The method is to place the calculated locus of the blue edge of the instability strip into the HR diagram in which the tracks of evolution off the main sequence onto the AGB for different masses and metallicities have also been placed. For each chemical composition, ranging from [Fe/H] = +0.4 to -1.7, the luminosity and the temperature at the blue edge of the strip for different masses are read from the HR diagram. The pulsation periods of stars at these luminosities, masses, and temperatures, for any given metallicity, are then calculated from some adopted pulsation equation.

Independent sets of tracks by the Geneva consortium (Meader *et al.*) and the Padua consortium (Chiosi *et al.*) were used, together with pulsation equations by the Padua group (1992), by van Albada and Baker (1972), and by Iben and Tuggle (1972). All of these authors use either the original Los Alamos opacities or the new Livermore (OPAL) opacities, both for the tracks in the HR diagram with and without overshoot, and for the calculation of the position of the blue edge of the instability strip. The results are nearly identical between all the groups, each with their different equations and precepts as to the opacity, the presence or absence of overshoot, and the method of calculating the onset of pulsational instability. The results were also independently confirmed in all respects in an entirely new study by the Basel group (Saio and Gautschy).

The result is the same as that obtained earlier by Iben and Renzini, Chiosi *et al.*, and Stothers, among others, that the zero point of the PL relation in M_{bol} is stable to better than 0.1 mag for metallicity changes by a factor of at least 100. To assess the effect in the V and I photometric bands, synthetic photometry has been done by Bell (Maryland), based on his model atmospheres, to give bolometric corrections to V and V-I colors for the same large range of metallicity at appropriate temperatures and surface gravities. Because the bolometric correction for V magnitudes is virtually independent of [Fe/H] for the range of temperatures, gravity, and metallicity that are appropriate for Cepheids, the P-L relation zero point in V is independent of [Fe/H] to within 0.05 mag (all for second crossings of the instability strip) over the same metallicity range. The variation in I is somewhat larger at 0.15 mag for a factor of 100 in metallicity, due to the differential blanketing effect in V-I. But a factor of 100 is 20 times larger than is encountered for the Cepheids in the calibrating galaxies used in the various HST calibration programs.

The most important conclusion from this work is that over the maximum metallicity range expected in these calibrating galaxies, the effect of metallicity variations cannot make a difference of as much as 0.02 mag in the V modulus, and of as much as 0.1 mag in the I modulus. The results have been prepared for publication by Sandage and Bell. Detailed tables of bolometric corrections to V and the variation of V-I colors with temperature, surface gravity, and metallicity have been prepared for the parameter-space appropriate for Cepheids with periods ranging from 2 to 100 days and for a range of metallicities from [Fe/H] +0.4 to -1.7.

Sandage, Saha, and Tammann have emphasized that determinations of reddening of the calibrating galaxies must only be made by determining the difference between the V and the I modulus using all the Cepheids in a given sample as a group, by applying the V and I adopted zero-reddening calibrations of the P-L relations. Under no circumstances must the highly uncertain V-I colors for individual Cepheids in the HST programs be used in some version of a P-L-C relation, Cepheid-by-Cepheid. If such a method using individual colors is attempted, the resulting mean distance moduli will always be underestimated. Many of the critics of the long distance scale in the current calibration program for SNe Ia parent galaxies with Cepheids have used this method.

Thompson and Kaluzny (Warsaw University Observatory) continued their study of detached eclipsing binary stars in southern nearby globular clusters. Extensive photometric monitoring of the cluster M55 revealed three such systems, all located at the cluster turnoff. Future detailed photometry and spectroscopic observations will be used to determine the distances to the systems, as well as the masses of the component stars. Monitoring of other clusters, as well as the follow-up spectroscopy and photometry, will continue in the coming observing seasons.

Phelps has continued his studies of old open clusters and the development of the Galactic disk, as well as of star formation within the Rosette Molecular Cloud. The major accomplishment of the old open cluster project was the publication of a photometric study of the oldest known open cluster, Berkeley 17. Another significant result was the identification of a new, metal-poor, outer-halo globular cluster, IC 1257 (Harris *et al.* 1997). An analysis of the first results from a comprehensive infrared and molecular line study of the Rosette Molecular Cloud, with Lada (Florida), was also completed.

2.2 Galaxies

Dressler has continued his work with Faber (UCSC), Richstone (Michigan), Kormendy (IFA-Hawaii), Lauer (NOAO), Tremain (CITA), and collaborators in the study of the nuclei of early-type galaxies with the HST. This year the group published the results of HST imaging data for a large sample of elliptical galaxies that show a clear dichotomy in the properties of the central regions of ''dynamically hot'' systems. The two types are those with a straight power-law increase in density down to the resolution of the HST (a few pc in many cases), as opposed to those that break to a more shallow increase in density (but none as flat as an isothermal core). The bright galaxies in the sample can show either type, and a clear separation seems to be present, but the fainter galaxies are all power-law systems. The group has speculated that the presence of black holes in these nuclei may be closely related to their central structures. In particular, it may be the dynamical encounter of central black holes from two interacting/merging nuclei that provides the energy to make a core structure, and prevent it from being destroyed in later accretion events.

Since the refurbishment of the HST, the group has obtained spectra of the very central regions in a few galaxies whose images indicated a high probability of harboring a black hole. These observations have confirmed the likelihood of massive black holes, 10^{8-9}, in each of these systems. The

group is now giving emphasis to the study of the demographics of black holes in galaxies. With good data on approximately 10 galaxies so far, it appears that the speculation by Dressler nearly a decade ago, that the black hole mass is, to first order, a constant fraction of the spheroidal mass in the galaxy, may indeed turn out to be true. However, significant scatter from this relation also suggests that there is much to be learned about the physical process of black hole formation and its connection to the birth and subsequent evolution of a galaxy.

Gallart, in collaboration with Aparicio (IAC, now also OCIW), Bertelli (Padova), Chiosi (Padova) and Freedman is continuing the analysis of the star formation histories of Local Group dwarf galaxies started during her Ph.D. studies at the IAC, using a technique involving a comparison of the observed color-magnitude diagrams (CMD) with synthetic CMDs computed from stellar evolutionary models. This year's results for the possible ''transition objects'' Pegasus and LGS 3 show that their star formation has not stopped in the last several hundred Myr, or even the past 1-2 Gyr. Rather, their current rate of star formation is similar to the average star formation over their lifetimes. The analysis of the HST observations of Leo I with the former collaborators plus Thompson and Mateo (Michigan) is revealing the peculiarities of this interesting galaxy. Although considered a dSph galaxy, it contains a large intermediate-age population, but very little (if any) old population.

Gallart, Aparicio, Dalcanton and Martinez-Delgado (IAC) have performed the first study of the stellar populations of the Antlia dwarf galaxy which was recently rediscovered and placed in the Local Group by Whiting, Irwin and Hau (1997), with observations from the 2.5m du Pont Telescope showing that it is a dIr galaxy very similar to LGS 3 and Pegasus.

Trager, Faber (UCO/Lick Observatory), Dressler, and Oemler discovered lensed galaxies at $z \sim 4$ with the Keck Telescope (Trager et al. 1997). From the weak or absent UV photospheric lines, it is estimated that these high-redshift galaxies are quite metal-poor. Although the star formation rates of these objects are rather large (2-75 solar masses/year), it is thought that these objects, rather than being primeval elliptical galaxies, are in fact the progenitors of the Population II components of local spheroids (ellipticals and bulges).

Using accurate age-dating techniques based on the absorption-line strengths of cluster galaxies at $z = 0.4$ and $z = 0.75$, as used in Trager's PhD thesis, Trager, Dressler and Faber have demonstrated (a) cluster ellipticals are younger than (most) present-day ellipticals, (b) they are coeval, (c) they formed at high redshift, $z > 2$, and (d) the population of cluster S0/Sa's is generally younger at these epochs than the elliptical population. Trager *et al.* have also found evidence that the metallicity of cluster ellipticals at these epochs may be higher than that of local ($z = 0$) field ellipticals. Unfortunately, there is little information on the stellar populations of local *cluster* ellipticals to make a direct comparison (see below).

Based on the same age-dating techniques, Trager and collaborators have found that local field ellipticals show a wide range of ages and a very narrow range of metallicities. In fact, local ellipticals in environments less dense than Virgo populate a narrow region in an age-abundance-velocity dispersion plane. When viewed from certain directions, this plane reduces to the Mg-sigma relation slope and spread and the color-magnitude relation slope and spread – both of which have long been thought to imply a strong mass-metallicity relation for elliptical galaxies. However, for field ellipticals, *age* seems to be the driving force behind the Mg-sigma and color-magnitude relations, with only a small component of metallicity. Interestingly, the age-abundance-velocity dispersion space is populated with different planes depending on the elemental abundance in question, which gives rise to [Mg/Fe]-age and [Mg/Fe]-sigma relations. Ongoing attempts are being made to interpret the implications of these planes for the formation histories of elliptical galaxies.

Trager has begun a spectroscopic survey of ellipticals and S0 galaxies in nearby ($cz < 15{,}000$ km s^{-1}) clusters using the Fiber Spectrograph on the 2.5m du Pont Telescope at Las Campanas. This survey will serve as a control sample for the high-redshift cluster galaxies and for comparison to the local field galaxies. As these spectra will also provide velocity dispersions (for at least the brighter galaxies), Trager has also begun an imaging survey in the optical and near-IR to determine scale lengths and colors of these galaxies in order to construct Fundamental Planes in various colors. The effect of stellar populations on the FP of early-type galaxies has still not been clearly demonstrated. Moreover, the predicted effect of stellar populations on the FP indicates that the FP-based distance scale should depend on the bandpass being used. Ultimately, these data (both photometric and spectroscopic) should be able to demonstrate the validity of such effects.

Bernstein and Small (IoA, Cambridge) have produced a catalog of low surface brightness galaxies from ground-based, CCD imaging data with a detection limit $r = 25.5$ mag/arcsec^2. The goal of this project is to obtain a local luminosity function inclusive of low surface brightness galaxies and hence to determine whether the population of low surface brightness galaxies is an important contributor to the luminosity and baryon densities of the local universe. These data will also delineate the distribution of galaxies in central surface brightness and scale length. To date, redshifts for roughly one third of the sample have been collected using the fiber spectrograph on the 2.5m du Pont Telescope at Las Campanas. The majority of galaxies with measured redshifts have luminosities 1-2 mag fainter than L^* and central surface brightnesses typically 2 mag/arcsec^2 fainter than the canonical Freeman value. The scale lengths are, however, comparable to those of high surface brightness galaxies.

Dalcanton has explored how the standard use of isophotal magnitudes may lead to severe biases in derived galaxy luminosity functions. Because the detected fraction of a galaxy's light is a strong function of redshift, surveys tend to misestimate the distance at which a galaxy can drop out of a sample. These biases cause systematic errors in the derived value of the maximum survey volume V_{max}, which lead to changes in the shape and normalization of the galaxy lumi-

nosity function. The biases become more severe for decreasing surface brightness galaxies, increasing redshifts, and larger point-spread functions. Because of the redshift dependence, the biases can also lead to the artificial appearance of evolution.

Dalcanton has also shown that a galaxy's measured isophotal magnitude and area can be related to a unique surface brightness and scale length, for a chosen galaxy shape. She has developed a formalism allowing these fundamental measures of the underlying galaxy physics to be estimated with better than 30% accuracy from easily measured isophotal quantities. The formalism is extremely useful for analyzing large galaxy catalogs, and can be used for selecting targets for redshift surveys, and for analyzing the underlying surface brightness distribution of galaxies, in a manner which is independent of the quality of the original imaging data.

Hashimoto and Oemler have been examining the environmental dependence of the properties of galaxies in the Las Campanas Redshift Survey. Galaxy structure has been characterized by central concentration, which is a proxy for bulge-to-disk ratio, and by asymmetry. Star formation rate is determined using the strength of the [OII] emission line. Since galaxy morphology, as represented by location along the Hubble Sequence, is the product, to first order, of bulge-to-disk ratio and star formation rate, they have been able to decompose the morphology-density relation (Dressler 1980) into two almost orthogonal components. This is not only the first study to consider separately these fundamental galaxy parameters, but is also by far the largest and most systematic study of the morphology-density relation.

These two components are found to vary with environment in a complex way. The mean bulge-to-disk ratio of galaxy populations increases steadily with increasing local density, irrespective of the larger scale environment (field, group, or cluster) in which the galaxies live. On the other hand, star formation rates, *at a fixed bulge-to-disk ratio*, depend on both local density and larger scale environment. Moreover, the dependence is different for low levels of star formation and for starbursts. This suggest that two different processes affect the star formation rate: (1) the suppression of normal star formation in denser environments, particularly in rich clusters, and (2) the excitation of starbursts in groups and poor clusters.

2.3 Clusters of Galaxies

Dressler and Oemler have continued their collaboration with Ellis and Poggianti (Cambridge), Couch (U. New South Wales), Smail and Sharples (Durham), Butcher (Netherlands Foundation for Research in Astronomy), and Barger (IFA, Hawaii) in the study of distant clusters, $z\sim$ 0.5, as a method of tracing the evolution of galaxies. With images from the Hubble space telescope, and faint galaxy spectra from the Hale, Herschel, and NTT telescopes, the group has endeavored to understand the structural and stellar population evolution of galaxies, with a particular emphasis on the role of galaxy environment. In addition to the publication of the complete morphological catalog, and studies of the gravitational lensing of these clusters and their inferred mass distributions, a paper on the evolution of the morphology-density relation for clusters has been accepted for publication, and a paper containing the complete spectral catalog is well along.

The morphology-density relation that is found for these younger cluster galaxies is similar to that found by Dressler (1980) for a sample of present-epoch clusters. Two striking differences are the large population of late-type galaxies, spirals and irregulars, which are responsible for the Butcher-Oemler effect, and the complementary deficit of S0 galaxies, suggesting that S0 galaxies, unlike the ellipticals, are a late product of environmental evolution. This latter conclusion seems consistent with the group's early finding that, based on very small scatter in $(U-V)_o$ distant cluster ellipticals, most of the stars in these galaxies formed very early, probably $z>2$. The group is now concentrating on modelling the stellar populations of the spectroscopic sample and integrating the complete data set into an analysis of the probable agents for the evolutionary changes seen in cluster galaxies. Additional HST time has been awarded to study the outer regions of one of the previously studied clusters. It is hoped that these additional data will provide a further clarification on the role of environment by providing morphological information on galaxies in high redshift clusters in regions of moderate rather than high density, which are further removed from the cluster center.

Mulchaey and Zabludoff (UCSC) have completed a redshift survey of twelve nearby groups using the fiber spectrograph at Las Campanas. They have found at least 20-50 group members to absolute magnitudes as faint as $M_B\sim$ -14 to -16 ($H_0=100$ /ks/ Mpc^{-1}) in each of the X-ray-detected groups, most of which were previously known groupings of less than five bright ($M_B\lesssim M_B$*) galaxies. The large number of group members, the significant early-type populations (up to $\sim$60% of the membership) concentrated in the group centers, the short group crossing times (less than 0.05 of a Hubble time), and the correspondence of the central, dominant elliptical with the optical and X-ray group centroids argue that the X-ray detected groups are real systems, not chance superpositions of unbound galaxies along the line-of-sight, and that the cores of these groups are virialized.

The X-ray groups also follow the same relationships found among the X-ray temperature (T), X-ray luminosity (L_X) and optical velocity dispersion (σ_r) of rich clusters. This result suggests that X-ray detected groups can be thought of as low-mass versions of clusters and that the extended gas component in groups can properly be called the intragroup medium, analogous to the intracluster medium in clusters. The non-X-ray-detected groups have fewer members and lower velocity dispersions than the X-ray groups. With the current dataset, Mulchaey and Zabludoff are not able to determine whether any of the non-X-ray groups are bound systems with little or no X-ray gas, or if they are all just superpositions of unbound galaxies along the line-of-sight.

Lubin, Postman (STScI), and Oke (DAO) have undertaken an extensive spectroscopic, photometric, and morphological study of nine candidate clusters of galaxies at $z\gtrsim 0.6$ with the highest redshift cluster at $z\sim 1.07$. The sample was chosen from the Palomar Distant Cluster Survey (Postman *et al.* 1996) and the Gunn, Hoessel & Oke (1986) survey. An

unprecedented volume of data is being collected for this cluster survey. For each cluster field, they are obtaining deep *BVRIK* photometry with the Keck 10m and the KPNO 4m telescopes, high signal-to-noise Keck spectra of over 200 galaxies per field, and high angular resolution imagery with the HST. Currently, the first two clusters at redshifts of $z\sim 0.84$ and 0.9 have been completed. The results indicate there is a great deal of diversity in cluster properties at these redshifts. These variations include differences in the color and morphology of the cluster galaxies, as well as the dynamical and structural properties of the cluster itself. At these redshifts, there are already well-formed, centrally-concentrated clusters with a large population of red, elliptical-like galaxies; however, there is also active cluster formation still taking place at this epoch. Evidence indicates recent merging of systems of galaxies which are dominated by blue, late-type galaxies.

Lubin and Mulchaey are currently performing a spectroscopic and photometric survey of approximately 50 candidate moderate redshift groups of galaxies. The candidate groups of galaxies were selected objectively from a Palomar optical/near IR ground-based CCD survey and deep optical imaging of a Southern field in the Las Campanas Redshift Survey. A matched filter technique which was originally developed for cluster detection (Postman *et al.* 1996) was adapted in order to search for groups of galaxies between redshifts of $z\sim 0.1$ and 0.5. The use of the automated detection algorithm means that an accurate selection function and estimate of the false positive detection rate can be generated through extensive simulations. Based on these simulations, they expect approximately 50-60% of the group candidates to be spurious detections. This implies that the redshift survey of the group candidates should spectroscopically confirm 20-25 poor clusters and groups of galaxies. This survey will create the largest sample of optically-selected, moderate redshift groups presently available. In conjunction with the redshift survey, Lubin and Mulchaey are acquiring deep multiband imaging of the two fields in order to do follow-up color analyses of the group galaxy populations. With these data, they are examining the group luminosity function, correlations between the galaxy population and global group properties, and the Butcher-Oemler effect, all as a function of redshift.

Kundic, Cohen, Blandford (Caltech), and Lubin are using the Keck telescopes to study several gravitational lensing systems. The goal of this project is to obtain accurate redshifts of the background source and the primary lensing galaxy, as well as to probe the redshift distribution of nearby galaxies. The results from the first two lensing systems, PG1115+080 and B1422+231, indicate that the primary lensing galaxy lies in a compact group of galaxies. This implies that a significant contribution to the lensing potential is provided by the group as a whole. These intermediate redshift groups are similar to the nearby Hickson compact groups of galaxies. They have several bright members within a projected radius of $\sim 35h^{-1}$kpc and velocity dispersions of several hundreds of km s^{-1}. These detailed studies of the lensing potential are being made in attempt to rule out certain classes of lensing models and improve the system's prospects for measuring the Hubble Constant.

Dalcanton, in collaboration with Zaritsky (UC Santa Cruz) and his students A. Nelson and A. Gonzales (UC Santa Cruz), has continued a program to do both spectroscopic and imaging follow-up of candidate $0.4\leqslant z\leqslant 1$ clusters of galaxies. The candidates were identified in an early EBL survey for low surface brightness galaxies, as well as in a much larger (150 square degree) EBL survey carried out with the 1m telescope at Las Campanas. Keck spectroscopy has proven that the clusters have redshifts between 0.4 and 1, as predicted. In an extensive program to obtain photometric information on distant clusters, very deep photometry for ~ 39 of the clusters in V, I, and (to a lesser extent) K', have been obtained using the 2.5m du Pont Telescope at Las Campanas, the 1.5m telescope at Palomar, and the Lick 3.5m. Based on current efficiency, roughly 300 clusters are expected in the final sample. Because of the large sample size, Delcanton and her collaborators are unable to obtain spectra for the majority of clusters, and are currently using a combination of photometry and spectroscopy for 16 clusters to calibrate a photometric redshift indicator which will be used for the final sample. It is expected that at least 50 clusters will be used in the final calibration. Ground based data and a NICMOS snapshot program have also been used to begin studying the optical and infrared properties of high-redshift brightest cluster galaxies over a wide, continuous range in redshift.

2.4 QSO's and Active Galaxies

With the help of N. Arav (Caltech), Weymann organized a workshop on ''Mass Ejection from AGN,'' which was held at the Observatories Feb. 19-21, 1997. The discussions covered observational and theoretical aspects of the outflow of matter from Seyfert galaxies and Quasars, and was attended by about 60 astronomers active in this field from the U.S. and abroad. This workshop has been published as volume 128 of the Astronomical Society of the Pacific Conference Series.

As a member of the HST Quasar Absorption Line Key Project team, Weymann further extended and improved previous versions of a maximum likelihood estimation formalism to correct for the biases in the data and derive the true redshift and equivalent width distributions of the Lyman α forest. All the data from the Key Project absorption line project (which have now been published or are in press), have now been included in the analysis. The results continue to indicate that over the redshift range 0.0 to about 1.4, the line density changes very little for the majority of line, though it may increase slightly for the very strongest lines and for those lines belonging to metal-containing systems.

Weymann, with Vogel and Veilleiux (Maryland), obtained further data on the Giovanelli-Haynes HI cloud, using the University of Maryland Fabry-Perot etalon and, for the first time, the 'final' version of the du Pont Reimaging Camera. The purpose of this observation is to detect, or set limits on, the local ($z\sim 0$) ultraviolet ionizing flux, by observing diffuse Hα in this isolated H$\sim$I cloud. Unprecedentedly low *formal statistical* (i.e. shot-noise limited) sensitivities were set ($<$ 1 milli-Rayleigh), but the data are still plagued by other sources in the data, the most serious of which are spu-

rious spectral features arising from faint stars which were not rejected by the current software. If in fact a limit even several times above that can be established without the detection of the Hα, it will be in serious conflict with predictions based upon counts of Quasars and extrapolations of their UV fluxes.

Mulchaey and Regan (DTM) have used a near-infrared imaging survey of samples of Seyfert and normal galaxies to study the role of bars in the fueling of nuclear activity. The active galaxy sample includes all known Seyfert galaxies in the Revised Shapely-Ames (RSA) catalog. The normal galaxies were selected to match the Seyfert sample in Hubble type, redshift, inclination and blue luminosity. K-band images were obtained for the galaxies at Las Campanas and Palomar. All the galaxies in both samples which are classified as barred in the RSA catalog are also barred in the near-infrared. In addition, $\sim$ 55% of the galaxies classified as non-barred in the RSA show evidence for bars at 2.1 μm. Overall, $\sim$ 70% of the galaxies observed are barred. The incidence of bars in the Seyfert and normal galaxies is similar, suggesting Seyfert nuclei do not occur preferentially in barred systems. In addition, a significant percentage of the Seyfert galaxies in the sample show no evidence for the presence of a bar even in the near-infrared. This suggests that large-scale kiloparsec bars are not a universal fueling mechanism in Seyfert galaxies.

McCarthy, Kapahi (NCRA, India), Persson and collaborators published the first in a series of papers describing a survey of radio sources selected at flux level near the peak of the 408MHz source counts. This program, the Molonglo Reference Catalog (MRC) 1 Jy Survey, is the largest sample of radio sources for which complete optical identifications are available. Nearly 20% of the 543 sources are identified with quasars, and the remaining 80% are radio galaxies that span a range of redshifts from 0.001 to 3.13. The median redshift for the radio galaxies is 0.75. The second and third papers in this series, which are nearing completion, describe the quasar sample, and the radio observations of the complete sample of 440 radio galaxies.

McCarthy and Kapahi have used the MRC sample to examine the evolution of the linear size of radio sources. By using the MRC and 3CRR samples, they are able to separate the dependances of source size on luminosity and redshift. Contrary to results found from the 6C 151MHz survey, McCarthy and Kapahi find a strong power dependence, with the linear size being proportional to the square root of the radio power. At a constant luminosity, the linear sizes decrease with increasing redshift by $(1+z)^{3.5}$. McCarthy and Kapahi also find that there are no significant differences in the projected linear sizes of radio galaxies and quasars within the MRC sample. This runs counter to the Barthel Unified Model for radio galaxies and quasars. McCarthy and Kapahi suggest the result derived from the 3CRR by Barthel was biased by small number statistics, and that the intrinsic dispersion in source sizes makes the Barthel test- of-orientation based unification models insensitive without sample sizes much larger than either the 3CRR or the MRC.

McCarthy, Miley (Leiden) and collaborators published the second paper in the series describing the 3CR snap shot survey. In this program, short images have been obtained of most of the 3CR radio galaxies and quasars with the Planetary Camera 2 on the Hubble Space Telescope. This paper presents images of 3CR radio galaxies with redshifts between 0.5 and 1.0.

Rush, McCarthy, Athreya (NCRA, India) and Persson completed a detailed analysis of one of the deepest HST images of a radio galaxy at $z > 2$. The WFPC2 images of MRC 0406-244 were used in conjunction with ground based Ly alpha and near-IR images to constrain physical models for the production of the rest-frame UV continuum in radio-loud AGN at high redshift. They find that for this object, scattering of nuclear continuum by dust is the most likely source of the spatially extended continuum. They also present evidence for gravitational lensing of one of the lobes of the radio source by a massive galaxy with a redshift of approximately 1.5.

McCarthy, Baum (STScI) and Spinrad (UC Berkeley) published their survey of the kinematics of extended emission line regions associated with the 3CR sample of radio galaxies. The sample covers the redshift range 0.3 - 2.5. Using these data and the low redshift survey carried out by Baum *et al.*, Baum and McCarthy are looking at the kinematic properties of the combined samples. They find that both the amplitude of the velocity fields and the velocity dispersions increase with increasing redshift. The amplitudes of the resolved velocity fields show a jump at $z = 0.6$, and Baum and McCarthy attribute this change to the transition of radio galaxies from a field to a cluster population. At redshifts less than 0.6, the typical amplitude of the velocity field is 300 km s^{-1}; at $z > 0.6$ the median value is 800 km s^{-1}. These large velocities suggest that the gas motions reflect the encounter velocities between the central radio galaxy and cluster members.

McCarthy, Fosbury (ESO) and Miley have begun a program to image 20 radio galaxies with $z > 2.0$ using the new near IR camera on HST. Five targets have been imaged to date. McCarthy *et al.* are preparing an ApJ letter describing one of the targets, MRC 0943-242. They find that contrary to the accepted model, the continuum that is aligned with the radio source is very red and dominates the integrated magnitude even at long wavelengths. The contribution of the host galaxy is only 10% at 0.6 microns, 25% at 1.5, and 30% at 2.2 microns. This result, if found in other radio galaxies, will have profound implications for our understanding of the hosts of radio loud AGN and early type galaxies at large redshifts.

2.5 Cosmology and Large Scale Structure

Sandage remained as PI of the HST calibration pro-ject to determine Cepheid distances to galaxies that have produced prototypical supernovae of type Ia. Cepheid distances were determined with the HST to NGC 4496A, parent galaxy for SN 1960F, and to NGC 4639, parent galaxy for SN 1990N. Adding the absolute magnitude at maximum for these two SN to the four previous calibrations (SN 1937C in IC 4182, SN 1895A and SN 1972E in NGC 5253, and SN 1981B in NGC 4536) gives six direct (i.e., of the parent galaxies themselves, rather than by a more indirect method via group

membership assumptions) calibrators using Cepheids for a mean absolute magnitude at maximum of $M(max) = -19.5 \pm 0.12$ for both B and V magnitudes. The very small dispersion is consistent with the known very small scatter in the Hubble diagram (log redshift vs. apparent magnitude) for the relative absolute magnitudes of prototypical type Ia SN. Applying this calibrated mean absolute magnitude at maximum to the relative Hubble diagram, which ties the local sample to the far expansion field (redshifts as large as 30,000 km s^{-1}), gives a Hubble constant of 56 ± 5 km s^{-1} Mpc^{-1}. This value is based on the assumption that ''Branch normal'' SNe Ia with $(B\text{-}V)_{max} < 0.20$ (to guard against large internal absorption) are perfect standard candles (not considering second parameters such as light curve decay rate).

Freedman continued as PI in the the HST key project to determine the Hubble constant. The overall goal of the project is to measure the Hubble constant by a variety of different techniques, with particular emphasis on eliminating sources of systematic error. The main focus is the measurement of distances to about 20 galaxies using Cepheid variables, with a consequent calibration of type Ia supernovae, type II supernovae, the Tully-Fisher relation, and a number of other secondary distance methods. During this year, a preliminary calibration for six different secondary methods has been established. In addition to the calibration of secondary methods, Cepheid distances to several galaxies in the nearby Virgo and Fornax clusters are being measured, and the sensitivity of the Cepheid period-luminosity relation to metallicity is being investigated. At this point, the Hubble constant is ranging from 65-80 km s^{-1} Mpc^{-1}, with an average of 73 ± 6 (statistical) ± 8 (systematic) km s^{-1} Mpc^{-1}. This new value is lower (but consistent within the uncertainties) than the one determined at the outset of the project (80 ± 17 km s^{-1} Mpc^{-1}), which was based on the distance to M100 in the Virgo cluster. The observations for this project will be complete by the end of this 1997, although final results and complete analysis of the data will require about 18 months.

Freedman and Madore (IPAC/Caltech) have calibrated the Cepheid period-luminosity (PL) relation at six wavelengths (BVIJHK), based on Hipparcos parallaxes which have recently become available for a sample of Galactic Cepheids. Unfortunately, the current parallax errors for the fundamental pulsators are very large (they range in signal-to-noise ratio from 0.3 to 5.3, at best), and they preclude an unambiguous interpretation of the observed differences. These differences may arise from a combination of true distance modulus, reddening, and/or metallicity effects. Currently extragalactic distances are calibrated relative to those of the Large Magellanic Cloud (LMC). These results suggest a range of LMC moduli between 18.44 ± 0.35 and 18.57 ± 0.11 mag (49 to 52 kpc). Comparing these calibrations with previously published multiwavelength PL relations, very good agreement is found at a level of 0.07 ± 0.14 mag, or $4 \pm 7\%$ in distance.

Phelps and Freedman have continued to search for Cepheid variables in galaxies which were observed as part of the HST Extragalactic Distance Scale Key Project. The major focus of this work has been the galaxy NGC 2090, which is a calibrator for the infrared Tully-Fischer relation. Thirty-four Cepheids have been identified in the galaxy, and a paper reporting this work is in final preparation. A search for Cepheids in the HST archival galaxy NGC 3368 has also been undertaken.

Sandage continued his collaboration with Tammann and Ph.D. student M. Federspiel (Basel) on the effect of observational selection bias in the determination of distances to galaxies using the 21 cm line width (Tully-Fisher) method. They completed a new study of the distance to the Virgo cluster using a complete sample of spirals in the Virgo Cluster Catalog (VVC, Binggeli *et al.* 1987), and a new calibration of the Tully-Fisher calibration based on the many new Cepheid distances becoming available from several HST programs (Saha *et al.* for the HST SNe Ia calibration; Freedman *et al.* for the HST Key Project). The Cluster Population Incompleteness Bias first predicted by Teerikorpi (1987), and discovered observationally (independently) by Kraan-Korteweg *et al.* (1988), is seen in the new Virgo study as a major signal using the complete Virgo cluster sample.

Their previous conclusion that the luminosity function must be sampled to a depth of 6 mag in a cluster before the incompleteness bias is reduced to zero remains the same. Errors of up to 0.8 mag in the distance modulus of any cluster are made when only the first several (two) magnitudes of the luminosity function is used with the TF method. This explains the large value of the Hubble constant determined in the decades of the 1980's and the first half of the 1990's by astronomers using the TF method in clusters without correction for the incompleteness bias. The modulus of the Virgo Cluster from these complete data, with cognizance taken of the decrease of the bias as the sample approaches completeness, is 31.6 mag (D = 20.9 Mpc). The tie of Virgo to the remote expansion field by the method of relative distances of remote clusters, i.e., relative distances to Virgo (Sandage & Tammann, 1990, Jerjen & Tammann 1993), gives H_o (global) = 58 km s^{-1} Mpc^{-1}.

Sandage, in collaboration with Tammann and Saha (ST ScI; hereafter STS), continued his study of the effects of possible second parameters with which M_{max} of SNe Ia might be correlated, possibly providing corrections to the precept that SNe Ia are perfect standard candles. Following the original suggestion of Pskovskii (1967, 1969, 1970, 1971, 1977, 1978), Phillips *et al.* (1994) proposed a large variation of M_{max} even for prototypical ''Branch normal'' SNe Ia depending on the decay rate of the light curve during the first 15 days after maximum. Tammann & Sandage (1995) showed that the proposed effect suggested by Phillips *et al.* was too large by a factor of 3 when applied only to the Branch normal subset of all SNe Ia.

During the report year, STS investigated other second parameters that themselves correlate with the δ m_{15} decay rate, but are easier to determine observationally and with higher accuracy than m_{15} because of the extreme photometry accuracy needed to determine reliable decay rates. These auxiliary second parameters are (1) Hubble type of the parent galaxy, and (2) (B-V) of the SN Ia color at maximum. The correlation of Hubble type with (relative) absolute magnitude of SNe Ia (determined from the relative Hubble diagram where the dispersion is exceedingly small–showing immediately that any second parameter correction must itself be

small) is well determined, and is as tight a correlation as is δm_{15} with M_{max}. The correlation with (B-V) at maximum is also tight and shallow, showing a difference of only 0.2 mag in M_{max} for a color change from -0.10 to +0.20 mag in $(B\text{-}V)_{max}$. The sense is that SNe Ia, with redder intrinsic B-V colors at maximum, are fainter than bluer ones.

Because the Hubble type of the parent galaxies of the six calibrators is known, and because colors for six of the seven available Cepheid calibrators (one additional calibrator in the Leo Group known in a companion galaxy, with Cepheids, to the parent) are known, the effect of applying the Hubble type or the color second parameters (the correction must not be applied twice) to the 59 SNe Ia in the extended ''Branch normal'' sample used by STS was determined. The effect on the Hubble constant that is determined by assuming SNe Ia are perfect standard candles was found by STS to be only 4%, considerably smaller than the 10-15% claimed and used from 1996 to the present by Phillips *et al.* After correcting for color/or Hubble type correlation using the seven Cepheid calibrators, the Hubble constant is 58 $\pm$ 5 km s^{-1} Mpc^{-1}. This compares with the ''no correction'' value of 56 $\pm$5 km s^{-1} Mpc^{-1}. The strongest proof that the Hubble constant must be substantially less than 65 km s^{-1} Mpc^{-1} derives from the requirement that M_{max} must not differ globally from the local value (i.e., where the calibrators are) over the range of 5,000 km $s^{-1} > V_{cosmic} >$ 20,000 km s^{-1} (Saha *et al.* 1997), as determined from the entire fiducial sample of 59 Branch normal SNe Ia used by STS via the relative Hubble diagram determined with them. The preferred value of $H_o = 56$ comes from making the local and global value of M_{max} of SNe Ia identical.

Bernstein, Freedman, and Madore have measured the extragalactic background light (EBL) in 1000Å-wide bandpasses centered at 3000, 5500, and 8000 angstroms using images from *HST*/WFPC2 and spectroscopy from Las Campanas. They report 2-sigma detections in each band. The total luminosity density of the universe based on this measurement is 2-3 times higher than that implied by measurements of the local luminosity function of galaxies. The EBL, including all galaxies fainter than $B \sim 24$, is about 2 times higher than the integrated flux from detected galaxies (differential galaxy counts) fainter than the same limit. These results imply that galaxy counts are incomplete in the identification of galaxies to the quoted detection limits, and also that the intrinsic flux of the galaxies which are detected is being underestimated. This is not a surprising result given the known surface brightness detection limits for most galaxy counts and redshift surveys. The detected EBL agrees with expectations based on the metal mass density found in galaxy clusters (which retain the metals produced by the stellar populations within the potential well of the cluster).

2.6 Instrumentation

Dressler has completed a conceptual design for the Inamori Magellan Areal Camera and Spectrograph (IMACS) for the first Magellan Telescope. The spectrograph is based on Shectman's design for a Gregorian secondary mirror and refractive collimator that gives excellent images over an exceptionally wide field of 0.5 degrees. Dressler has worked with Epps (UCSC) to develop optical designs for two cameras that will make use of this wide field. The first is an f/4 camera with a 17' field, 0.125''/15-micron pixel, and 0.2'' FWHM images. The second is an f/2.5 camera with a 27' field, 0.20''/pixel scale, and 0.35'' FWHM. It is expected that glass blanks will be purchased for the production of these cameras and the collimators before the end of 1997, and that fabrication of the lenses will begin in 1998.

Dressler has also completed a conceptual layout and design for the spectrograph, which uses the f/4 camera with reflecting gratings and the f/2.5 camera with transmission gratings (grisms). The conceptual design shows that the packaging of this instrument at one of the Nasymth platforms is feasible, and addresses such issues as guiding and field alignment, aperture masks, filters, grating selection, and stability. Work is now beginning in earnest to produce an advanced design which can be ready for the telescope in the beginning of 2000.

Persson and Murphy continued the design of two infrared instruments for Las Campanas. The first is the Carnegie contribution to a joint Carnegie/University of Cambridge project. The goal is to provide a wide-area near-infrared camera for the du Pont Telescope, particularly for survey work. The Carnegie part of the instrument is an optical converter unit that will feed light to the Cambridge detector system. The converter allows use of the detectors to longer infrared wavelengths than would otherwise be the case. It also provides for image stabilization at about 15 Hz. All the subsystems have been either designed or specified, and some construction has begun. The plan is to begin using the combined instrument on the telescope in December 1998.

The second instrument is the DDI near-infrared spectrometer for Magellan. The conceptual design is essentially complete, and work is proceeding to refine the optical design and specify the pixel scales and spectral resolutions. Work on the detector array electronics and computer system is ongoing. There are two main design features that should be important to the performance of this instrument. First, it is to be mounted on one of the Nasmyth platforms, and thus a cold field rotator leads to a gravity-invariant design. This should give the best possible sky subtraction, a significant point in certain parts of the spectrum where bright emission lines arising in the earth's upper atmosphere can seriously contaminate the spectra of the faint objects of interest. Second, the instrument will allow the use of multi-slits, so that the spectra of up to 25 objects can be recorded simultaneously.

As noted in last year's report, Weymann has built a wide field all-refracting reimaging camera for use at the Las Campanas 2.5m du Pont Telescope, and as also noted there, it was being modified to allow for its as a wide-field multi-object low dispersion spectrograph. These modifications have now been completed, and data began to be collected in this mode in July of this year. Code to select and generate slitmasks and to align the slitmasks was written and tested. Two low dispersion ($\sim$350 km s^{-1}) grisms are now available. Currently, film slitmasks are being used which limit the usable field because of errors in the the reduction factor and the laser printer. Experiments are being carried out by Lewis (Lick Observatory) to develop a technique for cutting 0.005

inch wide tapered slits with a computer controlled milling machine. With such masks, it is expected that the useable field for multiobject work will be about 20 arcmin x 14 arcmin. Data obtained to date suggest that spectra to roughly r=21 are quite feasible. Further improvements to allow drift-scannng in declination are also planned.

2.7 Magellan Project

Work continued on the construction of the first Magellan Telescope. Shectman continues as Magellan Project Scientist. In April, P. de Jonge retired as Magellan Project Manager, and was replaced by M. Johns, who has been Magellan Lead Engineer. de Jonge will, however, continue to play a large role in the project. The rotating structure of the dome has been assembled, the track shimmed level, the insulating panels and louvers installed, and the dome rotation and shutter drives put into operation. Possible problems caused by the flexure of the dome as it rides over the trucks are being investigated, and some remedial work on the louvers will be required in order to prevent leaks. Internal finishing and electrical wiring of the dome, control building, and aluminizing building were mostly completed. A completely new electrical generating system was installed on the mountain and local transformers and electrical distribution panels were installed at the Magellan site.

The mount was completely assembled at L & F Industries, and the telescope motions were tested under closed-loop servo control. All of the hydrostatic bearings were tested. The preloads to the vertical azimuth pads were adjusted by shimming. An occasional problem with the azimuth bearing will be fixed by scraping the azimuth track at the joints, where there is a local deformation of the surface caused by the tension in the bolts which hold the sections of track together. Prior to being installed on the telescope, the top-end ring, including the vane-end actuators and the secondary mirror cage, was completely assembled and preliminary tests of the control system for the vane-end actuators were carried out. Additional checks on the top-end ring will be conducted after the mount is disassembled.

The mechanical alignment of the main telescope axes, the mirror cell, and the instrument rotator axes was checked and found to be within specification. The mechanical functions of the mirror-handling cart were tested on the telescope using the real mirror cell, and the aluminizing chamber, mirror cell and cart were assembled as a unit and vacuum-tested. The Nasmyth instrument rotators were tested under servo control. Friction and windup in the servomotor gearboxes was found to degrade the performance to some extent, and a new type of gearbox will be tested on the Cassegrain instrument rotator. Two of the four honeycomb panels which are used to cover the primary mirror failed and are being replaced with improved units.

The back side of the primary mirror was ground and polished at the Steward Observatory Mirror Lab. The blank was inspected through the polished surface, and a number of areas with small cracks were treated by sandblasting and/or acid etching. Optical blanks for the f/11 secondary, tertiary flat and corrector/atmospheric dispersion compensator were received from Schott and Corning and are being polished at Contraves and Kodak.

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