Carnegie Observatories

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This report covers research done by Carnegie Observatories postdoctoral and scientific staff, and by visiting investigators at Las Campanas Observatory, during the one year period from July 1, 1995 to June 30, 1996.

1. PERSONNEL

Staff Members:

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

Staff Associates:

A. McWilliam

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, M. Rauch, A. Zabludoff

Postdoctoral Associates:

R. Phelps, C. Gallart, S. Landy, B. Rush, I. Smail

Predoctoral Fellows:

R. Bernstein

Support Scientists:

D. Murphy

Supporting Staff:

Pasadena (28 persons), Las Campanas (37 persons)

In January 1996, Leonard Searle stepped down after seven years as Director of the Observatories. He retired at the end of June, 1996. In June, Jerome Kristian was killed in a tragic accident, while flying an ultralight airplane. He was 63 years old at the time of his death, and had been on the Staff of the Observatories since 1968.

2. RESEARCH PROGRAMS

2.1 Stellar Astronomy

Preston has continued his search for spectroscopic binaries among 62 of the brighter blue metal-poor stars in an attempt to resolve the sample into blue straggler and unevolved main sequence populations. Survey stars typically were observed twice annually during the years 1992 through 1995. The original intent was to identify binaries by the use of a χ^2 statistic for each star. However, the data for many stars respond to application of the Lafler-Kinman (1965, ApJS, 11, 216) period-search technique. Periodic velocity variations, albeit with aliases produced by annual observing sessions, have been detected for 24 stars. Observations for the entire sample obtained in 1996 will remove some, but not all, of the aliases. Additional observations separated by 3 months will eliminate most of the remainder, thus producing orbital periods for all the detected spectroscopic binaries in this sample with periods less than about 1500 days.

Five of the blue metal-poor stars may be ultra-short period (SX Phe) variables and four more are possible velocity variables of undetermined nature. Because the number of SX Phe stars provides an independent way to estimate the size of the blue straggler component of the BMP sample, each of the SX Phe candidates was observed continuously over 2 to 3 hour intervals on two or more nights in July 1996. Reductions of these data are still in progress, but for one star, CS 22966-043, a large velocity variation of $\sim$35 km s^{-1} in a period of $\sim$55 minutes was noticed during the observations. Landolt (Louisiana State) confirmed this period (private communication) by performing *UBV* photometry of CD 22966-043 at CTIO in August 1996.

Persson, Krzeminski, Roth, and Murphy completed the observations for a program of establishing new near-infrared standard stars. All the data were collected at the Las Campanas 1m Swope Telescope and the 60-inch Palomar telescope. The project has three parts. The first uses the grid of seventh magnitude standards (Elias *et al.* 1982) to establish a set of 12 new standards near eleventh magnitude at *K*. These stars are all measured to accuracies better than 0.005 mag at *J*,*H*, and *K*. The final result of the second project will be a grid of 44 additional standards, tied to the first set, spread over the sky and suitable for use with the NICMOS infrared camera on the Hubble Space Telescope, as well as the upcoming 2Mass all-sky infrared survey. These stars will be measured to accuracies better than 0.01 mag. The third project will establish accurate transformations that will relate the colors of very red stars to those of photometric systems in use at other observatories.

Phelps and Lada (U. Florida) continued their program to investigate star formation within the Rosette Molecular Cloud (RMC). Initial results from a near-infrared survey using the Simultaneous Quad Infrared Imaging Device (SQIID) on the recently decommissioned KPNO 1.3m telescope reveal the presence of seven young embedded clusters in the RMC. All seven clusters are associated with IRAS sources and with molecular (^{13}CO) clumps, although not all IRAS sources or molecular clumps are associated with clusters. However, the majority of massive ^{13}CO clumps in the RMC are not associated with embedded clusters, suggesting that conditions other than high mass, such as high density, are needed for cluster formation. The spatial location of most of the clusters suggests that cluster formation may be triggered by the ionization fronts from the nearby HII region associated with NGC 2244. However, triggered star formation probably cannot explain the presence of all of the clusters, particularly the one farthest from the ionization front. It thus appears that more than one mechanism may be at work forming clusters in this cloud. Follow-up observations of the RMC embedded clusters have begun using the KPNO 4m telescope and the IRIM infrared imager.

Phelps, Lada, and Howe (U. Massachusetts) have also

begun a survey for dense gas (via emission from the J=2-1 line of CS) towards the 7 RMC embedded clusters using the Five College Radio Astronomy Observatory telescope. Preliminary analysis indicates that all 7 RMC clusters are associated with dense gas but the amount of dense gas varies among the clusters. Intriguingly, it appears that the dense cores associated with clusters closer to NGC 2244 have lower masses than cores associated with clusters further from the HII region, suggesting a possible age gradient.

McWilliam, in collaboration with Preston, Sneden (U. Texas), Cowan (U. Oklahoma), Burris (U. Oklahoma) and Armosky (U. Texas) have completed the reduction, analysis, and intepretation of CTIO 4m echelle spectra of the r-process rich star CS 22892-052. This star, originally identified by Preston (Beers, Preston & Shectman 1992, AJ, 102, 1987) as extremely metal-poor, was subsequently discovered to be rich in r-process elements in a spectroscopic survey of Preston's stars (McWilliam, Preston, Sneden & Searle 1995, AJ, 109, 2757).

The latest CTIO 4m echelle spectra resulted in two papers: Sneden, McWilliam, Preston, Cowan, Burris & Armosky 1996, ApJ, 467, 819, and Cowan, McWilliam, Sneden & Burris 1996, ApJ, (submitted). In Sneden *et al.* (1996) the results of the previous abundance analysis of this star were confirmed, but based on more lines from a larger sample of heavy elements: it is confirmed that CS 22892-052 has a huge overabundance of the heavy elements made by the r-process, identical to the solar system r-process abundance pattern. The large r-process overabundances in such an extremely metal-poor star ($[Fe/H]\sim -3$) suggest that the heavy elements in CS 22892-052 were made by a *single* supernova event.

In Cowan *et al.* (1996) the age of CS 22892-052 was determined from the abundance of the radioactive element thorium (Th), ratioed to the almost pure r-process element Eu. The minimum age of the star was estimated by comparison with the observed solar system Th/Eu ratio, which indicated a minimum age of 15 ± 4 Gyr. A variety of chemical evolution models of the Galactic disk were investigated in order to determine the r-process Th/Eu yield ratio from supernovae, consistent with the observed solar system ratio. All the chemical evolution models indicate that the age of CS 22892-052 is 17 ± 4Gyr.

McWilliam has acquired high resolution spectra of the previously unstudied 43 red giants in the BPS survey of metal-poor stars, using the Las Campanas 2.5m du Pont Telescope and Shectman echelle spectrograph. The spectra are typically characterized by a S/N of $\sim$15 per pixel at the 4077Å Sr II line. The objectives of this project are twofold: (1) to identify metal-poor stars which are rich in r-process elements, similar to the r-process rich star CS 22892-052, with the goal of pursuing any such stars to measure ages from the Th chronometer, and (2) to measure the dispersion in heavy element to iron abundance ratios among the metal-poor stars, in order to learn about homogenization processes in the early stages of Galactic chemical evolution. The lower than usual S/N for the spectra is more than sufficient to accomplish these two goals.

The spectra have not yet been analyzed; however, plots of the spectra at the telescope revealed (1) a large dispersion in the strengths of the heavy element lines of Sr II and Ba II at 4077 and 4554 Å respectively, indicating a dispersion in heavy element to iron ratio, and (2) one star with very strong heavy element lines, including the Eu II line at 4129Å, consistent with this star being r-process rich similar to CS 22892-052. If this second conclusion is confirmed in the detailed abundance analysis further spectra of this star will permit an age estimate to be made via the Th chronometer, and will make a significant impact on the uncertainty of the Th-chronometer age of the Galactic halo.

McWilliam, in collaboration with Castro and Rich (Columbia), have analyzed low S/N, high resolution, spectra of the most metal rich Galactic bulge giant known, BW IV-167; μ Leo, a well known bright super-metal-rich star, was also analyzed. The spectra were obtained by Filippenko and Spinrad (UC Berkeley) with the 10m Keck Telescope and HIRES spectrograph. This effort resulted in a paper: Castro, Rich, McWilliam, Ho, Spinrad, Filippenko, & Bell (1996, AJ, 111, 2439). The objective was to check the low bulge abundance scale of McWilliam & Rich (1994, ApJS, 91, 749, MR94). The abundance analysis, performed by three techniques, confirms the earlier results for these two stars by MR94, with $[Fe/H]\sim +0.45$ in both cases. Since this analysis confirms the abundance results of MR94 for their most difficult to analyze stars, the MR94 results are, in general, confirmed. Thus the Galactic bulge is metal-normal, and not metal-rich as was the consensus before McWilliam & Rich (1994).

McWilliam, Geisler (NOAO), and Smecker-Hane (UC Irvine) have continued to acquire echelle spectra for 58 Galactic bulge giant stars in Baade's Window, with the CTIO 4m telescope and ARGUS-echelle spectrograph. The spectral resolving power is 14,000 and the typical per pixel S/N is about 60, which is a factor of two improvement from 1995. The spectra are presently being reduced. The goal of this project is to resolve the difference between the high metallicity scale for bulge giants, as found by Geisler & Friel (1992), and the normal metallicity scale measured by McWilliam & Rich (1994). The investigators also plan to check the high magnesium and titanium abundances found by McWilliam & Rich (1994). In addition to the α element abundances, the [Eu/Fe] abundance ratio will be utilized as a diagnostic of the relative fractions of type II and type Ia supernova during the bulge chemical evolution, which can be used to indicate the bulge formation timescale. Temperatures for the program stars will be determined using infrared photometry acquired by McWilliam with the Las Campanas 1m Swope Telescope, and optical photometry from Geisler and Smecker-Hane, (based on CTIO observations).

McWilliam and collaborators Smecker-Hane (UC Irvine), Wyse (Johns Hopkins), and Ibata (U. British Columbia) have acquired high resolution (R$\sim$35,000), high S/N (70-100), spectra of three stars in the Sagittarius dwarf galaxy using the HIRES echelle spectrograph and Keck Telescope. The acquisition of more spectra is planned for 1997, with the objective of 12 stars in total. The goal of this experiment is to measure the chemical composition of a variety of stars in the Saggitarius dwarf galaxy. This dwarf, discovered by Ibata et al. (1994), is currently being accreted by the Galaxy,

and has been shown (by Smecker-Hane 1995) to contain stars covering a range in metallicity (-1.7 to -0.5 [Fe/H]) and age ($\sim$4 and $\sim$10 Gyr). The abundance ratio of α elements to iron, and Eu/Fe, will provide an important diagnostic of the relative frequency of type II and type Ia supernova taking part in the chemical evolution of this galaxy. This is possible as it is thought that type II supernovae produce iron, α elements (O, Mg, Si, Ca, Ti) and r-process elements (like Eu), whereas type Ia supernovae produce iron, but little else. The relative frequencies, combined with the age information of Smecker-Hane (1995), will enable a direct measurement of the type Ia supernova timescale. The type Ia timescale and the type Ia/type II model is widely accepted and used in many numerical models of galactic chemical evolution; thus, a measurement of the type Ia timescale will be of great utility. The additional goal is to measure the detailed chemical composition of a dwarf spheroidal galaxy, which has not previously been undertaken.

Krzeminski, in cooperation with Mazur and Sarna (Copernicus Astronomical Center, Warsaw), and Catalan (Univ. of St. Andrews) studied several precataclysmic binaries composed of a white dwarf and red dwarf pair in a close binary orbit. The most important are two systems: BPM 71214 and LFT 349 = RR Cae. For the former one the light modulation period of 4h 50m and an amplitude of 0.10 mag in the optical bands has been found; the latter one exhibits full eclipses repeating with a period of 7h 17m and light modulation of only 1% indicating a low temperature for the white dwarf.

Landolt (Louisiana State) continued working, in collaboration with Uomoto (Johns Hopkins), toward the very long-term goal of establishing faint broad-band photometric sequences in a band around the sky centered on the celestial equator. A Tek 2048 CCD was used at the 2.5m du Pont Telescope and a TI CCD was used at the 1m Swope Telescope. The eventual product of this program will be a set of faint standard star sequences on the Johnson-Cousins *UBVRI* photometric system. The areas undergoing the most intense observational scrutiny include selected Kapteyn Selected Areas as well as fields identified as potential standard star fields by M. Irwin in England. The latter fields contain potential red-blue stellar pairs. Much observing remains to be accomplished.

During marginal or non-photometric conditions, a photometric monitoring program was pursued. Prime targets under such circumstances were the globular clusters M80 and NGC 7492, for the characteristics of their variable star populations seem little known. Calibrated CCD data obtained at the 1m Swope Telescope have for the first time photometrically followed the hot hydrogen-poor variable star V348 Sgr from near minimum to near maximum brightness. A portion of these data were used in a study of the ultraviolet extinction curve for the circumstellar dust associated with V348 Sgr (Drilling, *et al.*, ApJ, 476, [Feb. 20, 1997, in press]).

Thompson and Kaluzny (Warsaw Univ. Obs.) have begun a study of detached eclipsing binary stars in southern nearby globular clusters. Extensive photometric monitoring of the cluster M4 has 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 followup spectroscopy and photometry, will continue in the coming observing seasons.

A long-term program of monitoring Supernova 1987A in order to search for the pulsar remnant was continued in 1995-96 by Middleditch (Los Alamos), Kristian, Kunkel, and Fazio and Eikenberry (CfA). While there is no clear evidence of any optical/near-infrared pulsar with a constant pulse profile and extremely predictable spin properties, there has been consistent evidence for a pattern of emission near the frequency of 467.5 Hz – a 2.14 ms pulsar candidate – since February 1992, when it was first detected in data taken at the LCO 2.5m du Pont Telescope. Further 2.14 ms signals which displayed a consistent and predictable spin-down ($\sim$2-3$\times10^{-10}$ Hz/s) were found over the several-year timespan through February 1996 in data taken with a variety of telescopes, data systems and detectors, at a number of ground- and space-based observatories (including LCO, and HST). There is also evidence in data, again taken by more than one telescope and recording systems, for modulation of the 2.14-ms period with a $\sim$1,000 s period which complicates the detection process. The characteristics of the 2.14 ms signature and its $\sim$1,000 s modulation are consistent with precession and spindown via gravitational radiation which are both caused by the same non-Maclaurin oblateness ($\sim10^{-6}$) of a young neutron star. The implied luminosity of the gravitational radiation exceeds that of the Crab Pulsar by an order of magnitude.

Thus, the 2.14 ms candidate pulsar, should it hold up, is an absolutely unique object, and provides the rosetta stone which helps explain the mysteries of SN1987A, including the blue supergiant nature of the progenitor, the extreme mixing of the elements, the rings, and the weak-field nature of the pulsar (which resulted from a coalescence of two white dwarf cores of two merged, massive stars). The wd-wd merger scenario also explains the overabundance of weak field ms pulsars found in the globular clusters.

Two papers on this observing program headed by Middleditch are nearing completion. Other collaborators on the large paper, based in large part on the LCO monitoring, include Lucinio (Caltech), and astronomers from UC Berkeley, Galway, Ireland, and NASA/Goddard. The two other authors on the shorter paper are from the University of Tasmania, from whose 1m telescope observations were made which confirmed the 2.14-ms candidate (and its $\sim$1,000 s modulation period) with the SNa *under* the pole. The HST results were included in this paper. The pulsar subsequently faded (after September '93) out of reach of the University of Tasmania 1m telescope before it could be monitored by larger telescopes like the 2.5m du Pont. This, partly, is the reason nearly three more years have passed before the observations (and authors) were all ready for publication.

Knezek is completing a project on star-forming regions in a metal-poor outer disk molecular cloud known as Maddalena's Cloud. She and her collaborators Adams, Ratcliff, and Winfrey (U. Michigan) have obtained *VRIJHK* photometry of 9 possible young stellar clusters selected by their IRAS emission.

Gieren (Universidad Catolica de Chile) has obtained high resolution, low S/N Echelle spectra of Cepheid variables in the LMC cluster NGC 1866. From these spectra, accurate radial velocities of the variables were derived which serve to test for cluster membership and can also be used for Baade-Wesselink distance determinations. He also obtained during the same time interval (December 1995 - January 1996) *BVRI* CCD images of NGC 1866 and five other, Cepheid-rich LMC clusters at the 1m Swope Telescope. Most of the images are now reduced using the DoPhot routine, and have yielded excellent optical light curves for about 10 Cepheids in NGC 1866. These data will now be supplemented with near-infrared photometry of the Cepheids and with additional radial velocities in order to derive distances and radii with an optical and near-infrared version of the Barnes-Evans technique. From this it is expected that the mean LMC distance modulus can be determined with an accuracy of 0.05 mag or better, independent of an assumed distance to the Pleiades. This research is being carried out in collaboration with Matias Gomez of the Universidad Catolica de Chile.

2.2 Galactic Structure

Phelps, along with Janes (Boston U.) and Friel (NSF) continued a program to probe the formation and development of the Galactic disk using old open clusters. Since their ages span the age of the galactic disk, these clusters are the ideal test particles for studying the evolution of the Milky Way Galaxy. Work has continued to improve photometric data for the old clusters. Phelps has used KPNO and Carnegie Institution telescopes to observe several of the oldest and faintest of the old clusters, and has completed an investigation of the oldest of the open clusters, Be 17, and the unstudied open cluster, Be 66. A new survey of candidate old open clusters has been initiated as has a new program to obtain near-infrared photometry of a subset of the known old open clusters. Willamette College undergraduate student Marc Kassis has also been involved in this research through the Research Experiences for Undergraduates (REU) program. His work on one cluster, 092-SC18, has recently been published. This cluster is of interest because previous estimates of its age ranged from 5 to 8 Gyr, putting it in the sample of only a dozen or so of the oldest clusters in the Galactic disk.

Reid (Caltech), together with Smail, Thompson, Yan (ESO), and Majewski (Virginia) have been studying the luminosity function of faint disk and halo stars. Over the last decade, considerable observational attention has been devoted to determining the frequency of low-luminosity M-dwarfs in the Galactic disk population – stars which have long been dark-matter candidates. In particular, if the mass function continues to rise as one reaches the hydrogen-burning limit (0.085 solar masses), the implication is that considerable mass may be hidden as 'brown dwarfs' or planetoids. The results, however, point to a mass function that is flat at the lowest masses, implying that there are insufficient stars (or brown dwarfs) to make a significant contribution to any of the missing mass problems.

Less attention has been given to the corresponding stars in the Galactic halo, the spheroidal distribution of metal-poor stars which were the first to form in the Galaxy. Until recently the few studies made, searching for M-subdwarfs in both globular clusters and the general field, suggested that, in contrast to the disk, the halo luminosity function increased rapidly with decreasing luminosity, apparently making these stars excellent missing-mass candidates. Unfortunately, recent work by Reid, Smail, Thompson, Yan, and Majewski shows that the field-star analysis errs in that essentially all of the low-luminosity stars are drawn from the Galactic disk, not the halo, while HST observations have cast doubt on the globular cluster studies.

One means of surmounting these problems is to search for nearby halo subdwarfs, stars within 50 parsecs of the Sun. These stars are outnumbered approximately 800 to 1 by stars in the galactic disk. However, halo stars have high velocities relative to the Sun, and can therefore be identified by searching for stars with high proper motions. Reid and Gizis (Caltech) have been putting together proper motion catalogues using plates taken as part of the POSS I and POSS II surveys (a 45-year baseline in time). Follow-up spectroscopic observations, with both the du Pont Telescope at Las Campanas and the Hale 200-inch at Palomar, allow the identification of the late-type M subdwarfs, which are characterised by strong absorption features due to calcium hydride and magnesium hydride. These stars can then be used to study the luminosity function. As yet, the analysis is not complete. However, the preliminary results suggest that, as with the disk, the halo luminosity function flattens substantially close to the hydrogen-burning limit, and that these stars are also inadequate to the task of supplying missing mass.

Majewski, Reid, Thompson, and University of Virginia graduate student Michael Siegel have continued their research into the classical starcount problem with a systematic survey of more than a dozen Kapteyn Selected Areas using the 1m Swope Telescope at Las Campanas. Observations now include B,V,R and I band CCD frames of 2 square degrees in each Kapteyn field with better than 5% photometric accuracy to $V=21.5$. Additional deep ($V<22$) starcount data are being generated by Majewski and Virginia undergraduate student Jamie Ostheimer in collaboration with Sandage. The latter data come from sky-limited Mayall 4m photographic plate scanned on the Virginia PDS microdensitometer. Majewski, Reid, Thompson, Yan and Smail have also recently analyzed deep *VRI* imaging data from the Keck 10m telescope (to $R\sim25.5$) as well as the Hubble Deep Field (to two magnitudes fainter). They show that the contribution to the faint starcounts from halo subdwarfs is limited to $R-I<1.0$, with redder stars being contributed from the Galactic disk and Intermediate Population II (IPII). They conclude that the previously found large upturn in the halo luminosity function for M(V) >10 is an artifact of contamination of disk and IPII stars for the intrinsically fainter stars.

Kunkel and Majewski have been searching for giant stars correlated to the HI Magellanic Stream. The presence or lack of a stellar stream would delineate between tidal and ram pressure stripping models for the Magellanic Stream.

Majewski and Cudworth (Yerkes Obs.) have continued their program to derive absolute proper motions with respect

to galaxies for a sample of distant (>20 kpc) halo globular clusters and dwarf spheroidals using the Baade and Sandage collections of photographic plates. In the past year, in collaboration with Ph.D. student Andrea Schweitzer (U. Wisconsin), they have derived proper motions for the Sculptor (Schweitzer *et al.* 1995) and Ursa Minor (Schweitzer, Cudworth & Majewski, in preparation) dwarf spheroidals. They are now beginning work on the Draco dwarf spheroidal galaxy and the globular cluster Pal 15.

Majewski has just begun a program on the 2.5m du Pont Telescope at Las Campanas to repeat photographic observations of the mid-declination (-15 to +15 degree) Kapteyn Selected Areas. The goal is to match the original plates taken by Seares, Kapteyn and van Rhijn at the turn of the century on the Mt. Wilson 60-inch telescope, for proper motions of exquisite (<0.1 arcsec/century) precision to V $\sim$19, tied to the extragalactic absolute reference frame. The 55 Selected Areas with $|b|>20$ degrees will allow an assessment of the halo two point correlation function in phase space as a means to search for and map large scale streaming motions in the halo.

During the report year, Sandage returned to the Mount Wilson Halo Mapping project discussed elsewhere (1983, ''Kinematics, Dynamics, & Structure of the Milky Way,'' ed. W. L. H. Shuter; Astrophysics & Science Library, Vol. 100, Reidel, p. 315), begun in the mid 1970's but delayed when the Carnegie operation of the 100-inch Mount Wilson Hooker reflector ceased in 1985. Four of the goals of the work are (1) determine the age of halo stars in situ at various heights above the Galactic plane, (2) provide corrections to the m_{pg} magnitudes to the limit of the Mount Wilson Catalog of 139 Selected Areas (Seares, Kapteyn, & van Rhujn, 1930, Carnegie Publications 402) for selected areas 28, 29, 45, 55, 57, 82, 94, 106, and 107, all but one of which are in the meridional plane ($l=0$ and $l=180$) of the Galaxy, (3) determine the density gradient and flattening of the halo in this plane, and (4) determine the ratio of halo main sequence stars to old disk stars in the solar neighorhood.

To these ends, photoelectric photometry on a $UBV(RI)_{MW}$ photometric system, completed in 1974-1980 with the Hooker Telescope, has been prepared for publication. The Seares *et al.* m_{pg} magnitudes all require corrections beginning at about $m_{pg}=15$. The true (Pogson-scale) magnitudes are fainter than the Seares magnitudes, reaching a correction as large as 1.5 mag at Seares *et al.* catalog magnitudes of 18.5 (the correct B magnitude at this level is 20) in some cases.

Photographic plates taken in B,V, and R with the Palomar 200-inch telescope and the Kitt Peak 4m reflector in the 1970's have been measured for each of the areas (except for SA 106), producing a complete *durchmusterung* of stars within the 15×15 arc minute fields of the 200-inch material, reaching close to the effective plate limit of $B=22$, calibrated via the photoelectric sequences using a Racine-Pickering wedge magnitude extender.

The color-magnitude diagrams clearly show the disk K and M star population beginning at $V=17$, whose population density is independent of the Galactic latitude. The halo component is also present, starting at $V=12$ whose population density is strongly dependent on Galactic latitude and the particular quadrant of the meridional plane, consistent with the solar neighborhood being displaced from the position of the Galactic center. The CM diagrams for each of the Selected Areas, and their analysis, are being prepared for publication.

Third-epoch photographic plates to determine proper motions have been taken by Majewski with the Palomar 200-inch, the Las Campanas 2.5m du Pont Telescope, and the Kitt Peak 4m reflector. These will be combined with the first epoch plates taken by Seares at Mount Wilson in 1910 to 1912 with the 60-inch telescope, and by Sandage in the 1970's at Palomar and Kitt Peak. The proper motion data will be discussed by Majewski and his students, who joined this phase of the halo mapping project during the report year.

The most striking feature of the CM diagrams of the Selected Areas is the, by now, well known sharp wall in the color distribution at $B-V=0.36$. Only a very few field horizontal branch stars are bluer than this well determined color limit. The presence of the wall in color was discovered first in the early Basel surveys in the 1970's and has been seen in all subsequent studies such as those by Weistrop, Gilmore & Weise, Majewski & Reid among others, and in the CMD of SA 45, previously published (1980, ApJS, 44, 219).

The $B-V$ color-limit of 0.36 for the halo field stars is identical with the bluest globular cluster stars at the termination point of the main sequence. This is the proof that most of the halo stars are as old as the old halo globular clusters. This fact, together with the recent discovery of the highly luminous, young, globular clusters in galaxies of the Amorphous class (cf. the Carnegie Atlas) identify the environment in which globular clusters first form. A well studied case is that of the two super-luminous, massive, star clusters in NGC 1569 at $M_B=-14$ (Arp & Sandage 1980). These objects are, beyond doubt, young, massive, globular clusters, formed only recently in a star-burst galaxy where the rate of star formation out of the molecular clouds is abnormally high at the present epoch.

With this evidence for the initial formation of young massive globular clusters, seen now in NGC 1659, NGC 625, NGC 1705, NGC 253, NGC 1275, and M82 among the Amorphous, or near Amorphous, galaxies listed in the RSA and the Carnegie Atlas, and with the evidence that the halo field stars and the halo globular clusters are among the oldest stars in the Galaxy that are nearly coeval, and with the evidence from Eggen, Lynden-Bell & Sandage (1962, ApJ 136, 748, ELS) that the Galaxy formed by collapse, and further that star formation for the hard central cluster takes place with 1% efficiency with an accompanying envelope of coeval but loosely bound individual stars (Larson, many places) such as seen directly in the h and χ Persi star cluster and the 30 Dor region of the LMC, it seems clear how the halo and the present globular cluster system in the Galaxy formed. As in NGC 1705, the high UV flux from the OB stars in the young globular clusters eventually either sweeps the halo clean of the unused gas, and/or the remaining gas falls to the plane by a dissipative collapse that builds the younger disk over time (still going on in the Galaxy?).

The picture, then, is one of a collapsing ELS envelope

containing ''noises'' that are the individual density fluctuations that will become globular clusters within that envelope (1990, JRASC, 84, 70). There is, of course, a distribution of the density-contrast spectrum. This contrast between the hard-collapsed objects that become the globular clusters and the smoother surrounding stars initially associated with each cluster, gives the halo field stars whose distribution is later smoothed out by random motions. The data supporting this picture are (1) the near constancy of the age of the halo field stars given by the ultra-sharp color wall at $B-V=0.36$ from the CMDs of the halo Selected Areas, (2) the near constant (to within 10% of the Galactic age) ancient age of the globular clusters, (3) the evidence of the environoment in which globular clusters form (by violent collapse) as seen in the present-day super-star clusters in most Amorphous galaxies such as NGC 1569, NGC 1705, and NGC 625, (4) the n-body simulations of the way galaxies with density fluctuations in the protogalactic mass fragment into individual units that are the proto-globular clusters within the overall collapsing envelope of the protogalaxy (Zurek, Quin, & Salmon 1988, ApJ, 330, 519), and (5) the models of Larson where the halo stars are those formed in the individual envelopes of the individual subunits, finally spread by random motions into a smoother distribution that is now the halo.

In this picture the initial halo was not built up by ''mergers'' of satellite galaxies from the outside, ''falling into equilibrium'' (Searle & Zinn 1978, ApJ, 225, 357), but rather by an accumulation of fragments already in the overall collapsing envelope of the Protogalaxy. Otherwise the present globular cluster system could not be understood. For sinking satellites to fall into the Galaxy by dynamic friction (a process that clearly operates today, based on the recent evidence from the Magellanic stream and the few ''external fragments'' now identified) requires already the existence of a massive halo *ab initio*.

2.3 Galaxies

Mulchaey, Zabludoff and Colbert (UCLA) are studying a unique and well-defined sample of isolated elliptical galaxies. The sample includes all elliptical galaxies in the RC3 catalog that do not lie within a projected radius of $1h^{-1}$ Mpc or ± 2000 km s^{-1} from any other galaxy. Deep optical and near-infrared images and long-slit spectroscopy (along the major and minor axes) have been obtained for all the objects in this sample. These data are being used to test the hypothesis that these isolated ellipticals are the remnants of a merged group of galaxies.

Zaritsky and Harris (UCO/Lick), Thompson, and Collier, and Hodge (U. Washington) obtained and are analyzing the first section of a digital *UBVI* photometric survey of the Magellanic Clouds. In their first observing run for the survey, they obtained a four filter survey of an area of 1.5 by 2.0 degrees from which they are developing their data reduction algorithms. So far they have obtained color-magnitude diagrams with several hundred thousand stars and studied the distribution of dust in the surveyed region using over 1000 OB stars. The survey is a three year project and will be made available to the community. Other collaborators are beginning to use the data to address other issues.

Miller (DTM/STScI) was involved in two projects to use optical and near-infrared colors of galaxies to determine their mean ages and metallicities. Miller, McGaugh (DTM), and Knezek used the 1m Swope Telescope to measure *JHK* magnitudes of low surface brightness galaxies. Also, Miller, Cote (ESO), and Skillman (U. Minnesota) used the 2.5m du Pont and 1m Swope telescopes to obtain *UBVI* and *JHK* images of dwarf galaxies in the Sculptor Group.

Freedman, in collaboration with Sakai (JPL), Madore (IPAC/Caltech), Lauer (NOAO), and Baum (U. Washington) have extended the use of the *I* magnitude of the tip of the first-ascent red giant branch (TRGB) as a distance indicator to nearby galaxies beyond 10 Mpc. The TRGB represents the core helium flash stage for low mass stars; observationally it is detected by measuring a discontinuity in the observed luminosity function. Using the *I* band, the TRGB method is very insensitive to metallicity and age differences in the stellar population. Studies by Lee, Freedman and Madore (1993, ApJ, 417, 553) and Sakai, Madore and Freedman (1996, ApJ, 461, 713) have applied the TRGB method to a total sample of 12 galaxies and find that the TRGB distances agree well with the distances to these galaxies using Cepheids or RR Lyrae stars. These studies conclude that the method is comparable in accuracy to the Cepheid period-luminosity relation (to a level of $\pm$ 0.1 mag). In addition, it can be applied to resolved galaxies with a range of morphological types. Moreover, it requires much less telescope time than do variable stars. In the most recent application of this technique, HST WFPC2 data for the giant elliptical galaxy NGC 3379, a member of the Leo I group, were analyzed, resulting in a distance of 11.4 $\pm$ 0.8 Mpc (Sakai *et al.* 1997, ApJ, in press). Calculating the relative distances between the Leo I group and Virgo and Coma clusters using several secondary distance indicators, a value of $H_0=69\pm 9$ km s^{-1} Mpc^{-1} is obtained.

Recent results from the HST on the morphologies of distant galaxies have been difficult to interpret, largely because very distant galaxies are being observed in the rest-frame ultraviolet (where the morphological properties of local galaxies are poorly understood). Using multicolor (*UBV* and *I*-band) CCD images of nearby galaxies observed with the du Pont Telescope, Freedman and collaborators Abraham, Ellis, and Lahav (Institute of Astronomy, Cambridge), and Madore (IPAC) have developed a technique to allow the morphological properties of local galaxies to be compared directly to those of distant objects. A template galaxy spectrum is fit individually to each pixel of a local galaxy image, effectively mapping the variation in the galaxy's spectral energy distribution across the face of the object. This information is used to account for cosmological bandshifting effects when simulating the appearance (as seen by HST) of distant counterparts to local galaxies. A comparison between the predicted and observed far-UV morphologies of a sample of spiral galaxies, imaged with the Ultraviolet Imaging Telescope, shows excellent agreement. The results from the artificial redshifting procedure have been used to calibrate an objective galaxy classification system, based on measurements of central concentration and asymmetry. This classification system is being used to determine the fraction of morphologically nor-

mal galaxies that are likely to appear irregular or peculiar in the Hubble Deep Field solely as the result of bandshifting effects.

Dalcanton, in collaboration with Spergel (Princeton) and Summers (Columbia), has developed an extremely effective first-order model for disk formation which explains the photometric properties and dynamics of both normal and LSB galaxy disks. The model also provides the means of predicting the joint distribution of disk surface brightness and scale length, which in turn can be used to predict the effect of surface brightness selection effects upon the luminosity function. The effects turn out to be large indeed, with the actual number density of L^* galaxies being more than a factor of two higher than what is measured in local surveys. The models also explain the Tully-Fisher relationship for both normal and LSB galaxies, as well as the systematic change in rotation curve shapes with surface brightness.

Dalcanton has measured redshifts for a complete sample of LSBs selected in the first large area CCD survey for LSBs. The well determined selection criteria have allowed her to completely quantify the detection efficiency of the survey, and thus to measure the absolute number density of this previously unconstrained population. The galaxies in the survey are at distances comparable to those probed by large galaxy catalogs, and have intrinsic scale lengths of $1.5-4\ h_{50}^{-1}$ kpc, also comparable to normal galaxies. She used the redshifts and the selection efficiency to calculate the number density in LSBs with $23<\mu_0<25$ Vmag/arcsec^2 and found $\mathcal{N}=0.02^{+0.03}_{-0.005}$galaxies /$h_{50}^3$ Mpc^3. Comparing the LSB number density to the number density of normal galaxies with either similar scale lengths or similar luminosities, the number density of LSBs with $23<\mu_0<25$ Vmag/arcsec^2 is comparable to or greater than the number density of normal galaxies. The measured LSB number density agrees well with the theoretical predictions of Dalcanton et al. (1996). The redshift-space distribution of the LSBs suggests that the trend for low surface brightness galaxies to have low small-scale correlation amplitudes continues to the low surface brightnesses covered in this survey.

Calzetti (STScI), Heckman (Johns Hopkins) and Meurer (Johns Hopkins), are attempting to understand the role of large-scale gas outflows in the evolution of starburst galaxies. Starbursts are highly inhomogeneous systems with complex dynamical interactions with the surrounding interstellar medium; the evolution of bursts of star formation cannot be adequately understood without using both spatial and spectral information. The program just started at Las Campanas Observatory will provide a full two-dimensional spatial description of the physical state of the starburst for a sample of galaxies. Medium-high (R$\sim$6500) resolution spectra centered at the wavelength of the Hα emission have been obtained at 10 different position angles for each galaxy, in order to investigate spatial variations of the velocity, density, pressure, and ionization of the gas.

Together with Telles, McGaugh (DTM) used the IR camera on the LCO 1m Swope Telescope to search for old stellar populations in starburst dwarf galaxies. The extreme formation activity of these galaxies masks the dim red light of older stars, making it difficult to test whether these are truly young objects with optical observations. The IR observations circumvent this problem and place useful constraints on burst evolution models which are only weakly constrained by optical observations. Young red supergiants can complicate the interpretation of even the IR data, but appear to be confined to the same region as the optical starburst. Outside this region, old stars were clearly detected. Though a pre-existing stellar component does exist, its total mass does not appear to vastly exceed that of the stars being formed in the current burst. Thus these galaxies do appear to be in a relatively early stage of their evolution.

Sandage, in collaboration with Carlson (Citrus College), Kristian, Saha (STScI), and Labhardt (Basel), continued the study of brightest stars in nearby galaxies as possible distance indicators. Photometry of the brightest stars in IC 4182, parent galaxy to the prototypical type Ia supernova 1937C, was published (1996, AJ, 111, 1872), comparing the zero points of the apparent magnitude scale to a limit of V = 22 made from Palomar 200-inch plates, with the internal calibration done with the Hubble Space Telescope. The magnitude scale from three sets of studies agree to better than 0.1 mag over the relevant magnitude range.

In a parallel study with Carlson and Kristian, CCD frames were taken for data on brightest stars in NGC 253, 247, 300, 1313, 7793, and IC 5152 obtained in two photometric observing runs at Las Campanas with the 2.5m du Pont Telescope. Many Cepheid candidates were found in NGC 1313 and IC 5152 during the extended observing interval of 40 days, encompassing two adjecent dark moon runs.

Sandage (1996, AJ, 111, 1; 111, 18) completed two studies of the luminosity functions of galaxies of various spiral morphlogical types and van den Bergh luminosity classes to assess the dispersion in M_B when the classes are severely restricted by type and class. Following the earlier method of Lemaitre (1927, 1931, MNRAS, 91, 483), Robertson (1928, Phil. Mag. 5, 845), and Hubble and Humason (1931, ApJ, 74, 43), each of whom used a calibrated mean absolute magnitude of galaxies to define a distance scale, the data for RSA galaxies were binned into the tighter class and luminosity subsamples to show that discrete luminosity functions do exist for each type and class, as originally discovered by van den Bergh. The luminosity functions were then calibrated in absolute units using the modern data for galaxies with known Cepheid distances.

Correcting for the evident observational selection bias using the method of Spaenhauer diagrams (Sandage 1994, ApJ, 430, 1, 13; Federspiel *et al.* 1994, ApJ, 430, 29) gives a Hubble constant $H_0=56\pm5$ km s^{-1} Mpc^{-1}. If the analysis had been made neglecting this correction for observational selection bias, an incorrect Hubble constant of 72 ± 5 km s^{-1} Mpc^{-1} would have been obtained. To make $H_0=85$ as advocated by proponents of the short distance scale would require that the present mean absolute magnitude zero point, based on the local calibrators, be in error by 0.91 mag. This is a 5 sigma difference, showing that the short distance scale is impossible if the Cepheid distances to the local calibrators are correct.

Kristian was lead PI on an HST program to assess the cosmological content of objects in three HST fields at high

Galactic latitude. These fields are not the same as the so called Hubble Deep Field survey by Williams *et al.* for which so many analyses have already appeared. The Kristian *et al.* deep fields are associated with the mJy radio source identification program in collaboration with Windhorst (Arizona State).

Morphological classifications of the very many galaxies in the three HST fields to a limiting magnitude of $F555W \sim 30$ had been completed by Sandage at the time of Kristian's fatal accident. Analysis of the statistics had been begun by Kristian. What can be said concerning the results is that the percentage of non-normal galaxies between $F555W = 22$ and $F555W = 28$ is much higher than at brighter magnitudes, such as in the POSS survey and/or the Shapley-Ames sample where less than 5% of the spirals are classed as ''abnormal.'' Conglomerants (i.e. condensations in a common envelope) are frequent, consistent with the galaxy formation picture discussed earlier in this report. Normal spirals are relatively rare (less than 20%). Normal-appearing red ellipticals are present in significant numbers (25%). In all respects these results are similar to the data being extensively reported by many astronomers for the Hubble Deep Field (Williams *et al.* 1996).

Giavalisco, Livio, Bohlin, and Macchetto (STScI) and Stecher (GSFC) have investigated the morphology of the distant galaxies observed with *HST* and compared them to that of their local counterparts observed at UV wavelengths with the Ultraviolet Imaging Telescope. Because of the cosmological redshift, distant galaxies are observed at wavelengths that are typically much bluer than those at which local galaxies are known. Due to a rather pronounced dependence of galaxy morphology on wavelength, assessing the degree of evolution in distant galaxies by comparing them to the present-day counterparts must be done with great care. The paper based on this work (1996, AJ, 112, 369) suggests that there is not secure evidence of morphological evolution in the brighter galaxies that *HST* has observed at about half of the life of the Universe.

Giavalisco, Koratkar and Calzetti (STScI) have studied the transport of Lyman-α radiation in star-forming galaxies from the IUE and *HST* archive. They found that Lyman-α emission in these sources is systematically obscured, even in galaxies with very little metal content, and cannot be used as a tracer of the star-formation activity. The results (1996, ApJ, 466, 831) show that the attenuation of the Lyman-α is not only due to dust extinction, but also to geometrical effects caused by resonant scatter by neutral hydrogen atoms that deplete the observable flux along the line of sight.

Knezek is working with Liu (U. Arizona), as well as Worthey (U. Michigan), to accurately determine the SED of spiral galaxies in the nearby universe. A volume limited sample of galaxies has been selected and integrated spectra and broadband photometry are being obtained for all.

Knezek, Schulman (NRAO), Bregman (U. Michigan) and Cox (U. Virginia) are studying the ionizing intergalactic radiation field using the galaxies NGC1300 and NGC4303. These galaxies have HI disks which extend well beyond the optical disk. Spectra of HII regions to determine abundances within the galaxies are being combined with HI maps and UV absorption line studies with HST of background quasars projected behind the HI disk to study the state of the gas in the outermost regions of the HI disk.

Knezek is involved in a project to study the interstellar media in the outer regions of elliptical galaxies, as well as the intergalactic media in clusters and groups of galaxies with Bregman (U. Michigan). They use background quasars as continuum light sources and search the UV with HST for absorption lines. The first HST spectra have just been obtained.

Knezek is working with Wroten (U. Michigan), Lawrence, and Cruz-Gonzalez (Universidad Nacional Autonoma de Mexico) to study the optical and NIR properties of gas-rich low surface brightness galaxies. They will determine the underlying star formation history of these poorly understood systems.

2.4 Clusters of Galaxies

Mulchaey, in collaboration with Davis (U. Alabama), Mushotzky (NASA/GSFC) and Burstein (Arizona State) have used ROSAT data to search for the presence of X-ray emitting diffuse gas in poor groups of galaxies. A diffuse component was found in 25 of the 48 groups studied. X-ray luminosity does not correlate well with the optical richness, blue luminosity, or the velocity dispersion of the group. In contrast, there is a strong correlation with the percentage of early type (E and S0) galaxies. All of the groups with an extended intra-group medium have high percentages of early-type galaxies and over half of these systems appear to contain no spirals at all. Furthermore, all the X-ray detected systems contain at least one elliptical with a blue luminosity of $L_B \sim 5 \times 10^{10}\ L_\odot$ or greater. There are several possible explanations for the correlation between spiral fraction and the presence of diffuse hot gas including the idea that the spiral-rich groups represent superpositions of galaxies, that they contain a relatively cool intra-group medium, or that the formation and evolution of spiral-rich groups is fundamentally different than that of elliptical-rich groups.

The X-ray observations are also being used to estimate the total masses of these systems. There is a large range in the derived gas masses, but in general the mass in the X-ray emitting gas is comparable to or less than the mass in the galaxies. Despite the large range in gas mass, there is a very narrow range in total group mass, with most of the groups having a mass of $\sim 2 \times 10^{13}\ M_\odot$ out to the radius for which X-ray emission is detected by ROSAT. The ratio of observed luminous mass (i.e. galaxies + hot gas) to total inferred mass in poor groups is rather low ($\approx$ 5-30%), implying these systems are dominated by dark matter.

Mulchaey and collaborators have also analyzed new ROSAT PSPC observations of the NGC 2300 group. Spatial analysis of this data reveals that the diffuse X-ray gas can be traced to at least $25'$, (0.33 Mpc, $H_0 = 50$ km s^{-1} Mpc^{-1}). The surface brightness of the gas is well fit with an isothermal King model with a core radius of $28^{+1.27}_{-0.93}$ ($56.5^{+16.8}_{-12.3}$ kpc) and a β of $0.410^{+0.027}_{-0.021}$. The temperature of the gas, as determined from fitting a Raymond-Smith plasma model to the spectral data, is $0.97^{+0.11}_{-0.08}$ keV. There is no

evidence for a tempertaure or abundance gradient in this group.

Mulchaey and Zabludoff are combining optical broadband images with fiber spectroscopy taken at the LCO 2.5m du Pont Telescope to study the optical properties of poor groups of galaxies known to contain a hot intra-group medium. The purpose of this study is to determine the group membership and luminosity function to fainter magnitudes than any previous study of poor groups. The optical data will be combined with the ROSAT PSPC data to determine the baryonic fraction of these systems.

Lubin, Postman, Gunn, Oke, Schneider, and Hoessel have completed the Palomar Distant Cluster Survey, which produced the largest, statistically complete sample of distant clusters with estimated redshifts between 0.2 and 1.2. Candidate clusters of galaxies have been objectively identified from the resulting galaxy catalog through a matched filter technique which uses both positional and photometric data simultaneously. The resultant sample contains 79 clusters and is complete to $z\sim 0.6$. The average Palomar cluster has a surface density profile of $r^{-1.4}(r\geqslant 0.15h^{-1}\mathrm{Mpc})$ and a core radius of $0.05h^{-1}\mathrm{Mpc}$. There is some evidence that the slope of the surface density profile *steepens* with increasing redshift. At present, it is difficult to constrain existing cosmological models; however, flat CDM models predict detectable profile evolution, while open models do not. Clear color evolution is observed in the Palomar clusters with regards to the red, early-type population and the Butcher-Oemler effect. In clusters at $z\sim 0.5$, the ridge line of early-type galaxies in the color-magnitude diagram has shifted bluewards compared to the ''no-evolution'' prediction. By $z\sim 0.8$ there are no cluster galaxies as red as present-day ellipticals. In addition, the fraction of blue galaxies is strongly correlated with the estimated cluster redshift. The measured blue fractions are consistent with those found previously.

Lubin, Postman (STScI), Gunn (Princeton), Oke (DAO), Schneider (Penn. State), and Hoessel (U. Wisconsin) have begun an extensive observational program on the best distant cluster candidates in the Palomar Distant Cluster Survey and the Gunn, Hoessel & Oke (1986) sample. They are currently analyzing HST observations on 7 of the most distant clusters at $z\sim 0.7-1.1$. Coordinated spectroscopic, optical and infrared observations of all of these clusters are being carried out at the 10m Keck Telescope and the Kitt Peak 4m telescope.

Lubin and Bahcall (Princeton) have examined the mass-to-light ratio as a function of scale from single galaxies to groups and clusters of galaxies. The M/L_B increases with radius up to $\sim 100-200h^{-1}\mathrm{kpc}$, the largest extent of individual galaxies and the size of small groups. They find that ellipticals may have mass-to-light ratios which are ~ 4 times larger than spirals when extended to these large scales. Groups and clusters of galaxies with radii larger than $\sim 200h^{-1}\mathrm{kpc}$ have approximately constant mass-to-light ratios between ~ 100 and $400hM_{\odot}/L_{\odot}$. They suggest the possibility that no significant excess of dark matter exists in these systems; their mass may be accounted for by the mass of the member galaxies (both their luminous and dark matter components, including their large halos) and the mass of the baryonic intracluster gas.

Dressler and Oemler, in collaboration with Ellis and Barger (Cambridge), Couch (UNSW, Australia), Smail and Sharples (Durham), and Butcher and Poggianti (Netherlands Foundation for Research in Astronomy) have been using COSMIC at the 200-inch Hale Telescope at Palomar, and EMMI on the ESO NTT telescope to obtain spectra of faint galaxies in clusters at z $\sim$ 0.5. These data are essential for interpreting studies of morphology of distant cluster galaxies, done with Hubble Space Telescope (HST) images obtained by the team; the spectra allow for identification of cluster members and measuring the recent history of star formation in galaxies with unusual or disturbed forms.

With these new data, which include approximately 250 new cluster members in the HST fields and approximately 1000 spectra of galaxies in adjacent fields – the target of ongoing study with HST – the team has found that (1) disturbed morphologies with starburst or post-starburst spectra are usually disk galaxies, and that (2) clean samples of cluster member elliptical galaxies have a very small scatter in $(U-V)_o$, indicative of a tight synchronicity of formation ages, and/or early formation, $z>2$ for most of the stars. A morphology-density relation is found for these younger cluster galaxies, similar to that found by Dressler (1980, ApJ, 236, 351) 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.

Dalcanton has used the smoothed optical background to identify very high redshift clusters. At large redshifts, a cluster or group may be too distant for the galaxies within the cluster to be detected individually in a short exposure. However, the light from these ''undetected'' galaxies still modulates the surface brightness of the background sky. Dalcanton has shown that distant clusters can appear as $10''-1.5'$ sized fluctuations in the surface brightness of the extragalactic background light (EBL). The fluctuations have central surface brightnesses between roughly 26 and 28 mag/arcsec^2 (in V) for clusters between $z=1$ and $z=2$, and are brighter than the random fluctuations produced by field galaxies. While such low surface brightnesses are difficult to achieve with direct high-resolution imaging, they are easily reached in short exposures through smoothing the sky in very flat drift-scanned CCD images.

Dalcanton, in collaboration with Zaritsky (UC Santa Cruz) and Luppino (Hawaii), has begun a program to do spectroscopic follow-up of candidate $z\geqslant 1$ clusters of galaxies using the Keck Telescope. 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 at the LCO 1m Swope. The clusters have proven to be at redshifts between 0.4 and 1, as predicted. In an extensive program to obtain photometric information on distant clusters, they have obtained very deep photometry for ~ 30 of the clusters in V, I and K', using the LCO 2.5m du Pont, the Palomar 60-inch, and the Lick 3.5m.

Zabludoff, Smail, Couch (UNSW, Australia), and Edge (IoA, Cambridge) are studying a complete X-ray selected

sample of 25 rich clusters in the intermediate redshift region, $0.07 \leqslant z \leqslant 0.14$, combining deep, multi-color photometry and high signal-to-noise, multi-object spectroscopy to obtain a detailed view of the cluster galaxy populations and cluster dynamics. The first stage of this project uses the wide-field imaging capabilities of the LCO 1m Swope Telescope to image 2×2 degree regions in B and R centered on ~ 25 rich clusters. The imaging observations of the first 15 of these clusters were undertaken in two runs totalling 17 nights during 1996. The typical image quality was 1.3 arcsec FWHM and the observations reached 5σ limits of $B = 22.5$ and $R = 21.5$. These images are currently being reduced and analyzed to allow the team to start on the spectroscopic stage of the project in 1997. This will use the 400-fibre 2dF multi-object spectrograph on the 3.9m AAT to acquire high signal to noise spectra of ~ 1000 galaxies within the infall radius of each cluster. Their hope is to complete the imaging of the final 10 clusters in their sample in 1997.

When compared with studies of both local clusters and HST observations of more distant systems, this complete sample will provide a continous view of the evolution of galaxies in high-density environments, allowing one to track the changes which have transformed the active Butcher-Oemler populations of these regions as seen at $z > 0.2$ into the passive inhabitants seen today. In addition, the survey is matched to the selection function of the 250,000 galaxy 2dF Galaxy Redshift Survey, to permit the study of galaxy populations as a function of environment – from the low-density field to the most massive collapsed structures in the universe. Finally, the catalogue is sufficiently large that the statistics of cluster mergers, as identified from the detailed kinematic and X-ray imaging information, can be used to test the infall rate and hence the value of Ω_0.

2.5 Quasars, Active Galaxies, and Intergalactic Matter

McCarthy and Persson, together with Kapahi, Athreya, and Subrahmanya (NCRA, India) and van Breugel (IGPP, Livermore) have completed the optical identification of sources in the MRC/1Jy radio source survey. More than 96% of the sources are identified to R=25 or K=19. The remaining sources are primarily confused sources or occulted by foreground stars. A paper presenting all 553 of the radio galaxy identifications, positions and photometry will appear in the November 1996 issue of the Astrophysical Journal Supplement. Kapahi has submitted papers on the radio source properties and the 110 quasar and BL Lac identifications. Redshifts for 90% of the quasars and 75% of the radio galaxies have been obtained using facilities at the Anglo Australian Observatory, Las Campanas and Cerro Tololo. McCarthy, van Breugel (IGPP), Kapahi and Athreya (NCRA, India) are preparing a paper discussing the spectroscopy of the radio galaxies; Kapahi, Hunstead (AAT), and Baker (MRAO, UK) are preparing a paper on the quasar spectroscopy. Athreya, Kapahi, McCarthy and van Breugel have a paper in press in the MNRAS showing that the cores of distant radio galaxies have steep radio spectra. This result can be understood as the result of relativistic motion of material in the core shifting a strongly peaked spectrum to centimeter wavelengths.

Rush, McCarthy, Persson and Athreya (NCRA, India) have carried out a detailed study of one of the MRC radio galaxies, 0406-244 at $z = 2.44$. Rush *et al.* combine HST images in two colors with ground-based g, r, i, J, H, K and Ly alpha images to examine the alignment effect in this source. They find that it is difficult to produce the requisite optical depth for Thompson scattering based models for the alignment effect, although dust scattering models are energetically viable. A paper presenting these results has been submitted to the ApJ.

McCarthy, Baum (STScI) and Spinrad (UC Berkeley) have analyzed long-slit spectra of more than 40 3CR radio galaxies to extract the velocity fields in the extranuclear emission-line regions. Velocity fields with amplitudes of 800 - 1000 km s^{-1} are increasingly common at high redshifts. There is little evidence for rotation although many systems show apparently organized motions on scale of 10's of kpc. A paper presenting the data will appear in the October issue of the ApJ supplement. McCarthy and Baum are preparing a paper with a comparison of the high and low redshift galaxy samples.

McCarthy and Miley (Leiden, NL) with Baum, Sparks, Biretta, Macchetto, de Koff, and Golombek (STScI) have obtained HST images of many of the $z > 0.5$ 3CR radio galaxies in the snap-shot mode as part of a snap-shot survey of the entire 3CR catalog. A paper with the $z > 0.5$ sample is in press in the ApJ supplements. De Koff et al. (same as above) have published the intermediate redshift sample in the July issue of the ApJ supplement and Baum *et al.* have submitted a paper on the low redshift ($z < 0.1$) sample.

Fosbury (ESO), McCarthy, Eisenhardt (JPL) and Werhle (IPAC) have begun a program to observe a sample of 3CR radio galaxies and quasars with the long-wavelength photometers on ISO. The first set of observations were taken in June of 1996. Di Serego Alighieri and Cimatti (Arcetri, Italy) with McCarthy and Fosbury have begun a program of optical imaging polarization observations of intermediate and high redshift radio galaxies from the MRC/1Jy survey. Four nights of data were obtained on the ESO 3.6m and 2.1m telescopes in February of 1996.

McCarthy and Lawrence (JPL) have assembled a composite radio galaxy spectrum by combining spectra of dozens of radio galaxies obtained over several years at Lick, Kitt Peak, Palomar and Cerro Tololo. Thirty two emission features are identified in the composite spectrum which covers rest-frame wavelengths ranging from 800 to 5500Å. A publication with these results is in press in the AJ.

In collaboration with Morris and Grey (DAO), Weymann reports that the results of a 4-year monitoring campaign of the prototypical Seyfert galaxy NGC4151 were carried out. The data were obtained using the Hubble Space Telescope High Resolution Spectrograph as part of the HRS GTO program. The data consisted of high (420 km s^{-1}) resolution spectra centered on the C IV and Mg II emission lines, supplemented by lower resolution Faint Object Spectrograph data. The goal was to study the variations in the absorption superimposed upon these emission lines, which has been known to exist for some time and which had been studied

previously at lower resolution and signal-to-noise from the IUE satellite.

These high resolution data show that the profile is very complex and requires at least 7 different components to model the observed profile. Previous studies emphasized the variability of the absorption and, while variations in the strength of the absorption are observed, what is rather remarkable is that over the period covered by the data (about 4 years) there is no detectable *dynamical* change in the components. Quantitatively, it is possible to set very stringent limits on any secular accleration that occurred over these 4 years. These limits, in turn, may be interpreted in terms of models involving clouds exposed to radiative acceleration following ballistic trajectories, or alternatively to clouds, constrained by drag forces, nearly co-moving with a wind. In either case, one infers characteristic distances for the clouds which are much larger than the scale of the broad emission line region, which conventional wisdom has identified as the site of the absorption. From HRS archival data, the Si II ground state and fine structure lines were also observed, and in principal the ratio of these two lines can set independent constraints on the physical conditions and locations of the clouds, but the signal-to-noise of this archival data was not adequate to do this reliably.

As a member of the HST Quasar Absorption Line Key Project team, Weymann extended and improved previous versions of a maximum likelihood estimation formalism to derive the behavior of the density of Lyman α absorption as a function of redshift and equivalent width. The most recent result, which still does not include data from most of the highest redshift QSOs for which the Key Project Team has acquired data, are broadly consistent with their previous results. In particular, the results indicate that over the redshift range from about 0 to 1.0 the rate of increase in the Lyman α line density is very gentle – substantially more gradual than that found in the redshift range accessible to ground-based observations. At redshifts above about 1 the rate of evolution appears to steepen, though the data are not adequate to indicate whether this increase is smooth and gradual or abrupt. Future modeling and observations will be needed to determine whether this behavior is consistent with a single general origin for the Lyman α clouds or whether two quite different mechanisms are involved. A preliminary account of this work was presented by Jannuzi *et al.* at the Boksenberg Fest on Cosmology, Cambridge, England, July 1996.

Mulchaey, in collaboration with Regan and Kundu (U. Maryland) have recently completed a large near-IR imaging survey of Seyfert and normal spirals. K-band images were obtained for 55 galaxies using the LCO 2.5m, the Palomar 1.5m and the Kitt Peak 2.1m. These images are being used to search for the presence of bars or oval distortions which could facilitate the transfer of mass from galactic scales to the nucleus. The near-IR images reveal bars in many galaxies classified as unbarred based on optical images. However, a small fraction of the normal and active galaxies show no evidence for bars even in the near-infrared.

Mulchaey, Mushotzky (NASA/GSFC), Burstein (Arizona State) and Davis (U. Alabama) have investigated the possibility that an intra-group medium in spiral-rich groups of galaxies can be detected through absorption in QSO spectra. For the expected temperature, density, and metal abundance of the intra-group medium, various high ionization lines should be detectable. In particular, at T $\sim 2 \times 10^6$ K, O VI, Ne VIII, Mg X and Si XII lines will be seen. Strong Lyman series lines are also expected. A collisionally-ionized gas at these temperatures will not produce much C IV and N V absorption, requiring a multi-phase medium to produce spectra which show all of the above ions. In addition, some lines of sight will likely pass only through the intra-group gas, producing pure [** lq **]''high ionization''rq absorption systems (i.e. O VI lines without associated C IV and N V lines). Recent HST and Keck observations have revealed the presence of absorption lines with some of the properties predicted for the intra-group medium in spiral-rich groups.

Oemler and a large team of collaborators at Yale University, Indiana University, Universidad de los Andes (Merida, Venezuala) and CIDA (Venezuala) have begun a program to survey the equatorial sky in order to produce a well-defined sample of 10^{5+} QSO's. It is hoped that this QSO sample will, in turn, yield a well-defined, statistically complete sample of dozens of gravitationally lensed QSO's to use for various cosmological studies. To perform the survey, a CCD camera has been designed and built at Yale and Indiana which contains a mosaic of 16 Loral 2048 CCD's. This camera will be mounted in the CIDA 1m Schmidt Telescope and used in drift scan mode to produce multi-color direct imaging or objective prism spectra covering about 200 square degrees per night. An online data system constructs an object catalog and performs preliminary reduction of the data. An offline data pipeline has been built to search the data set for various classes of astronomical objects, including QSO's, and to detect QSO's which show signs of multiple images. First observations with this system are expected in late 1996.

Campusano (Universidad de Chile), Newman, Clowes and Graham (Univ. of Central Lancashire) successfully started the spectroscopic observations for a new quasar survey over 140 deg^2 of sky using the multi-object fiber spectrograph on the 2.5m du Pont Telescope at Las Campanas. The survey is in two areas: a program area of 100 deg^2 centered at (1950) 10^h40^m, $05°00\prime$, and a control area of 40 deg^2 centered at 11^h14^m, $-27°30\prime$ about 33° away from the other. The aims of their survey are: (i) to determine the full extent, membership and statistical significance of the large ($\sim 200h^{-1}$ Mpc) quasar group discovered by Clowes & Campusano (1991) in the center of the program area; (ii) to measure the density contrast of the quasar group; (iii) to search for sub-clustering in the group and test the hypothesis that all small-scale ($\leqslant 10h^{-1}$ Mpc) quasar clustering is attributable to large groups; (iv) to analyse the clustering of quasars in general in the survey; (v) to identify and characterise any other large quasar groups using the minimal-spanning tree method of Graham *et al.* (1995). The full survey should produce a homogeneous sample of nearly 1500 quasars.

Survey candidates were selected by ultraviolet excess from UK Schmidt Telescope plates digitised on the SuperCOSMOS machine. During the 3 nights of their first spec-

troscopic run at Las Campanas, they surveyed about 18 deg ^{2}, which led to the discovery of 143 new quasars with redshifts in the 0.2- 2.7 interval, and to the recovery of the 43 previously-known quasars in the area satisfying the selection criteria. Preliminary analysis suggests that the sample is complete to an apparent magnitude $B = 19.7$. Forty-two narrow emission-line galaxies were also revealed in this first run.

2.6 Cosmology and Large Scale Structure

Persson, Madore (IPAC), Murphy, Freedman, Roth, and Krzeminski continued three observational programs aimed at removing systematic uncertainties in the zero-point of the extragalactic distance scale. The first program involves near-infrared (JHK) measurements of 90 Cepheids at 15 phases in the Large Magellanic Cloud. This database, when complete, will minimize uncertainties due to reddening and metallicity for Cepheids, and will be a primary stepping-stone out to Cepheids in galaxies to be observed with HST/NICMOS. The second program involves H-band observations of Cepheids in two external galaxies; the observations of IC1613 and of NGC300 are nearly complete, with about six phase points per Cepheid, and 11 Cepheids per galaxy. The third program will secure the distances to all galactic open clusters that contain Cepheids. Main-sequence fitting of the infrared color-magnitude diagrams to those of the Pleiades main sequence is the goal; the observations are complete.

As part of the Hubble Space Telescope Key Project on the Extragalactic Distance Scale, Freedman, in collaboration with Phelps (OCIW), Madore (IPAC/Caltech), Kennicutt, Turner, Bresolin, Harding (U. Arizona), Mould, Gibson (MSSSO), Graham (DTM), Stetson (DAO), Hughes (RGO), Silbermann, Sakai (JPL), Ferrarese, Ford (JHU), Hoessel, Han (U. Wisconsin), Huchra, Macri (Harvard/CfA), Illingworth, Kelson (UCSC) have now discovered Cepheids in 11 spiral galaxies, completing over half of the observations and data reduction required for the Key Project. The overall aim of the Key Project is to determine a value of the Hubble constant with a total (random + systematic) error of less than 10%. These galaxies include M81, M101, M100, NGC 925, NGC 3351, NGC 4414, NGC 4725, NGC 3621, NGC 7331, NGC 1365, and N4548. Recently, a sample of over 50 Cepheids has been discovered in the Fornax cluster galaxy, NGC 1365. From apparent V and I period-luminosity relations, a reddening-corrected distance of 18.5 $\pm$ 0.19 Mpc is determined. Their results to date yield a value of $H_0 = 73 \pm 6$ (statistical) $\pm$ 8 (systematic) km s^{-1} Mpc^{-1}. The systematic error takes into account a number of factors including: the present uncertainty in the zero point of the Cepheid period-luminosity relation of $\pm$5% (or equivalently the uncertainty in the distance to the LMC), the potential uncertainty due to metallicity, also in the Cepheid period-luminosity relation at a level of $\pm$5%, an uncertainty which allows for the possibility that the locally measured H_0 out to say, 10,000 km/sec may not be the global value of H_0 of $\pm$7%, plus an allowance for a scale error in the photometry that could affect all of the results of $\pm$3%. Their current adopted value for H_0 is 73 $\pm$ 10 km s^{-1} Mpc^{-1}. At the present time, the total uncertainties amount to about $\pm$15%. This result is based on a variety of methods, including a Cepheid calibration of the Tully-Fisher relation, type Ia supernovae, a calibration of distant clusters tied to Fornax, and direct Cepheid distances out to $\sim$ 20 Mpc.

Dressler, in collaboration with Tonry and Blakeslee (MIT), Ajhar (NOAO), and Luppino (U. Hawaii) continues to obtain very deep (several hour) direct images of E and S0 galaxies in the Local Supercluster and beyond, out to distances corresponding to recession velocities of $\sim$4000 km s^{-1}, with the Tek 2 CCD at the du Pont Telescope. These data are used in analysis of ''surface brightness fluctuations (SBF),'' a technique perfected by Tonry, that uses the Poisson distribution of surface brightness in patches limited in size by atmospheric seeing, to determine the distance to an early-type galaxy to $\sim$5%, a substantial improvement over methods like $D^n - \sigma$ (or Tully-Fisher for late types). The data, all of which has yet to be analyzed, have nonetheless yielded interesting results, including a confirmation of the remarkably large and coherent peculiar velocity ($\sim$1500 km s^{-1}) of elliptical galaxies in the Centaurus cluster(s), found first by Lynden-Bell *et al.* (1988, ApJ, 326, 19). A map of unprecedented accuracy has been made of peculiar velocities in the Local Supercluster, with the substantial amplitude of $\sim$300 km s^{-1} found for the Local Group's infall toward the Virgo Cluster.

The team has derived and adopted a calibration for the SBF technique (Tonry *et al.*, 1996 ApJ, in press), including a reliable correction for the age of the stellar population, which is measurable as a relationship between the absolute magnitude of the characteristic fluctuation and the galaxy (V-I) color. The very accurate relative distance measurements for galaxies and groups extending far out into the Hubble expansion field have been tied to various local calibrators, including the Cepheid results from HST by Freedman and collaborators, in order to derive the Hubble constant. The data favor, with a high degree of confidence, the ''short distance scale,'' and give a Hubble constant $H_o \sim$ 80 km s^{-1} Mpc^{-1}.

Sandage continued as PI of a group consisting of Saha (STScI), Tammann and Labhardt (Basel), and Panagia and Macchetto (STScI) that are working to determine Cepheid distances to parent galaxies that have produced prototypical type Ia supernovae (SNe Ia). The Hubble diagram (apparent magnitude at maximum vs. log redshift) for such SNe Ia (as a class called ''Branch normal,'' 1993, AJ, 106, 2383) is very tight. The dispersion is less than 0.3 mag in B and in V. Hence, such supernovae are the best standard candles known. Calibration of their mean absolute magnitude at maximum calibrates their Hubble diagrams, which can then be read at redshifts well beyond all local velocity anomalies, and further can be tied directly to the kinematic frame of the cosmic microwave background. This group considers this method to the Hubble constant to be the most powerful available because it cuts to the core of the distance scale problem, circumventing all uncertain steps in tying local galaxies and clusters to the cosmic velocity frame.

During the report year, Cepheids were found and measured in NGC 4639, parent galaxy to the Branch normal SN 1990N (1996, ApJ, 460, L15). The true distance modulus of NGC 4639 based on its Cepheids, corrected for internal ab-

sorption, is $(m-M)_o = 32.02 \pm 0.20$, giving the calibration of the peak absolute magnitudes for SN 1990N as $M_B(max) = -19.42 \pm 0.23$, and $M_V(max) = -19.33 \pm 0.23$. Combining these data with the five other SNe Ia that have been calibrated previously in the project gives the mean values of $<M_B(max)> = -19.47 \pm 0.07$, and $<M_V(max)> = -19.48 \pm 0.07$. Combining these mean magnitudes with the Hubble diagrams for well observed Branch normal SNe Ia in *B* and *V* (1993, ApJ, 415, 1) read at remote redshifts, gives $H_0(B) = 56 \pm 4$ km s^{-1} Mpc^{-1}, and $H_0(V) = 58 \pm 4$ km s^{-1} Mpc^{-1} using no second-parameter corrections for decay rate or other effects suggested by the critics of the method. Consideration of such second-order corrections that depend on Hubble type of the parent galaxy, color of the SNe Ia, and/or light curve shape shows that such ''corrections'' can increase H_0 by not more than 8%. Proposals for HST time in cycles 7-9 that include SNe Ia that are not quite Branch normal are designed to assess directly, via Cepheid calibrations, the reality of various second-parameter corrections suggested the critics of these results.

In view of the near perfect agreement of the determination of $H_0 = 57$ via the supernovae route with that through calibration of the Hubble type and van den Bergh luminosity class luminosity functions giving $H_0 = 56$ (AJ, 111,1, 18), and the disagreement with those results that espouse the short, or the intermediate distance scale, (i.e. $H_0 > 70$), Sandage, Tammann, and Saha have studied the causes of the differences.

The large Cepheid distance to NGC 4639 ($D = 26 \pm 3$ Mpc) is a factor of 1.5 larger than $D = 17 \pm 2$ Mpc to the spiral NGC 4321 (M100), also determined from Cepheids (Freedman *et al.* 1994, Nature, 371, 757). Both galaxies have, at various times, been said to be members of the Virgo cluster. In view of the large difference in their distances, each, or even taken together, cannot define the distance to the Virgo cluster core, but rather prove that the spirals surrounding the more compact elliptical galaxy cluster core form an extended halo about that core with a much larger back-to-front ratio than has been heretofore assumed. Sandage, Tammann, and Saha conclude that the premise used by Freedman *et al.* (1994) to derive $H_0 = 80$ from the M100 data is not supported by the NGC 4639 result.

The second problem with interpretation of the M100 data, giving the Key Project team its short distance scale, concerns the correct value of the cosmic expansion velocity of the Virgo cluster core. Sandage & Tammann (1996, ApJ, 464, L51) claim, following Jerjen and Tammann (1993, A&A 276, 1), that the Virgo redshift, tied directly to the microwave frame, is 1187 km s^{-1} rather than 1404 km s^{-1} used by Freedman *et al.* Taking the Tully-Fisher distance to the Virgo core as $m-M = 31.6$, based on 50 spirals (Federspiel & Tammann 1996, submitted), and the aformentioned Virgo redshift of 1187 km s^{-1} gives a total correction as a factor of 1.5 by which $H_0 = 80 \pm 17$ must be decreased, giving $H_0 = 55 \pm 17$ from the M100 Cepheid experiment (Freedman *et al.* 1994) alone.

Sandage and Tammann then examined the precept also adopted by the Key Project group that tying the distance scale to the Coma cluster and assuming that the Coma cluster is at rest relative to the CMB expanding cosmic frame (i.e that no random or streaming motions exist for the Coma cluster), defines the cosmic kinematic velocity frame. They have found that this is not correct (ApJ, 464, L51). It was also noted that the similar error has been made by many other authors (eg. Tanvir, *et al.* 1995, Nature, 377, 27; Whitmore et al. 1995, 454, L730), leading each to an incorrect large value for H_o.

In a similar way, the announced intermediate value of $H_0 = 70$, based on the Cepheid distance to NGC 1365 (Freedman *et al.* 1996, Baltimore conference report) has been considered in the critique. As with M100 and NGC 4639 in Virgo, the precept by the Key Project group is that NGC 1365 defines the distance to NGC 1316, parent to the two Branch normal SNe Ia 1980N and 1981D, thereby calibrating them. This precept gives a SNe Ia mean calibration that is considerably fainter than that from the six calibrations at $M_{max} = -19.5$ just described, and further requires that the mean has the large spread of 0.8 mag, contrary to the proof via the Hubble diagram of a much smaller dispersion of M_{max} for normal SNe Ia. Because of this, Sandage, Tammann, & Saha consider that the result of the NGC 1365 Cepheid experiment, interpreted to give $H_0 = 70$ by the Key Project group, is not proved.

A similar analysis was made of the precepts used by Whitmore et al. (1995, ApJ, 454, L73) for, (1) the cosmic velocity of the Virgo cluster, tied to Coma as if it has no random or streaming motions, and (2) the absolute magnitude of the turnover of the globular cluster luminosity function for the globular cluster system in the Virgo elliptical NGC 4486. Sandage & Tammann (1996, ApJ, 464, L51) showed that the value of $H_0 = 78$ obtained by Whitmore *et al.* could be reduced to $H_0 = 62$ as an *upper* limit when an alternate calibration of M_{max} of the globular cluster luminosity function is used, based on revised RR Lyrae star absolute magnitudes that are required from the Oosterhoff-Arp-Preston period-metallicity relation, and using the Jerjen/Tammann cosmic velocity for the Virgo cluster core.

Giavalisco, together with Steidel (Caltech), Pettini (RGO), Dickinson (STScI) and Adelberger (Caltech), have discovered the most distant population of normal galaxies ever observed, placed at redshifts $z > 3$, corresponding to an epoch when the universe was only $\sim$15% of its present age. These galaxies are very young and are actively forming the bulk of their stars, at a rate about 10 times faster than what is currently observed in the disks of spiral galaxies. Searched without success for more than a decade, young galaxies are expected to provide the much needed empirical information to understand how galaxies started to form in the universe. The authors were successful in identifying them thanks to a new photometric technique designed to detect distant galaxies from their Lyman-continuum discontinuity and Lyman-α forest absorption. The spectroscopic confirmation of these faint sources was carried out using the 10m Keck Telescope. The results of this research have been published in the Astrophysical Journal (1996, ApJ, 462, L17).

Giavalisco, Steidel (Caltech) and Macchetto (STScI) have carried out a morphological study of star-forming but otherwise normal galaxies at redshifts $z > 3$ using the *HST* with

the Wide-Field Planetary Camera 2. These are the most distant normal galaxies ever observed and they are providing, for the first time, direct empirical data on the epochs and mechanisms of galaxy formation. The *HST* images show that these systems are characterized by a very compact and relatively regular morphology. From the analysis of the light distribution, the authors could determine that a large fraction of the stars that are being formed in these young galaxies, $\approx$50%, are concentrated in their innermost regions, whose size is only a few kiloparsec. The authors conclude (1996, ApJ, in press) that it is very likely that they have identified the progenitors of the present-day bright spiral and elliptical galaxies at an epoch when they were assembling the stars of their central regions, i.e. their bulges and cores.

Giavalisco has been among the astronomers who carried out the Hubble Deep Field images. In this experiment, *HST* has been looking at the same field for 10 consecutive days, obtaining the deepest optical image ever in the history of astronomy. The images were taken in 4 different filters so that color information was available. The vast majority of the galaxies in the HDF are so faint that no spectroscopic information can be obtained, even with the largest telescopes. For these objects the multi-band images obtained in the HDF will be the only information available about their spectral energy distribution for decades to come, offering a unique glimpse of the faintest and most distant galaxies in the Universe. A description of the Hubble Deep Field experiment appears in the 1996 October issue of the Astronomical Journal.

Giavalisco, with Steidel (Caltech), Dickinson (STScI) and Adelberger (Caltech) have measured the redshifts of distant galaxy candidates in the *Hubble Deep Field* using the Keck Telescope. They were able to confirm that the optical color of these sources was indeed typical of very distant galaxies observed during an intense phase of star formation. The authors have confirmed (1996, ApJ, 112, 352) that the color photometry adopted in the HDF experiments is very sensitive to isolate young and distant galaxies.

Shectman, Oemler, and Landy, working with collaborators Kirshner (Harvard), Lin (Toronto), Tucker (AIP), and Schechter (MIT) have completed a first analysis of the results from the Las Campanas redshift survey. Redshifts have been obtained for 26,000 galaxies distributed in six 1.5×80 deg strips, three in the North galactic hemisphere and three in the South. The average radial velocity is 30,000 km s^{-1}. The luminosity function exhibits a small but evidently significant deviation from a Schechter function. The faint end slope is characterized by a value for the parameter alpha ~1. The luminosity density leads to an estimate for the critical (closure) mass-to-light ratio of ~1500. The incidence of emission lines is very strongly dependent on luminosity. Conspicuous features in the galaxy distribution are evident at scales up to 50 or perhaps $100h^{-1}$ Mpc, but on larger scales the distribution is much more homogeneous. The correlation function approaches zero at a scale of about 40 Mpc, and fluctuates within the range ±0.02 out to scales of several hundred Mpc. The three-dimensional power spectrum clearly changes slope, and probably turns over, at a wavelength of 100 Mpc. An analysis of the two-dimensional power spectrum shows some evidence for enhanced power at this scale. There is clear evidence for weaker clustering among bluer galaxies or those with emission lines. All of the data from the survey has been made available to other investigators via the internet.

2.7 Instrumentation

As briefly noted in last year's report, a wide field all-refracting reimaging camera was designed for use at the Las Campanas 2.5m du Pont Telescope. This instrument has now been fabricated and its first trial was carried out during September 1996. The performance appears to be consistent with the design goals.

A 6 element wide-field collimator produces a collimated beam with a 70 mm diameter pupil over a 25 arcmin diameter field. A 6 element camera plus field flattener reimages this field onto a Tektronix 2048×2048 CCD with 0.78 arcsec pixels. The instrument is usable over the pass band from about 3750Å to about 9000Å. The optical design minimizes distortion so that the instrument can be used in drift scan mode. The optical design is by Dr. Harland W. Epps, Lick Observatory, collimator fabrication by Mr. Gerard Pardeihlan, camera fabrication by Tucson Optical Research Corporation, broad-band AR coatings by QSP Inc., Anaheim, California and mechanical design by Mr. J. Alan Schier.

The initial uses involved a search for high redshift QSOs in candidate fields for the proposed southern Hubble Deep Field survey, using the slitless grism mode, and a study of the Hα emission from the Magellanic stream and Hα emission from edge-on early-type galaxies (both in collaboration with Dr. Stuart Vogel, University of Maryland) using the University of Maryland Fabry-Perot interferometer.

Further modifications will allow the introduction of a slit mask wheel for wide-field multi-object low dispersion spectroscopy, and possibly the capability of drift scanning in declination.

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