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I. STAFF AND STUDENTS

William Baum, formerly of the Lowell Observatory, joined the faculty with the rank of Research Professor. He is a member of the *Hubble Space Telescope* Wide Field Camera team, and will work actively on analysis of WFC data. During the Academic Year 1990–91, the teaching faculty of the Department included Professors Balick, Böhm, Böhm-Vitense, Boynton, Brownlee, Hodge, Hogan, Lake, Margon, Nelson, Sullivan, Szkody and Wallerstein. Prof. P. Hodge spent one quarter on sabbatical, including meteoritic field work in Australia. The research faculty members were Drs. S. Anderson, D. Brown, J. Brown, J. Deeter, A. Noriega-Crespo, and X. Wu. Twenty-four graduate students were registered as members of the Department in 1990–91. In the past year, the Ph.D. degree was awarded to S. Morgan (dissertation advisor Prof. E. Böhm-Vitense); she has accepted a position on the faculty at the University of Northern Iowa. Prof. B. Margon is departmental Chair.

II. RESEARCH

This report covers research during the academic year 1990–91.

a. Solar System

P. Hodge analysed soil samples that he collected from the surroundings of five relatively recent meteorite craters in central and western Australia. In spite of considerable effort, no microscopic meteoritic material was detected in the soil of the Snelling Crater, from which no larger meteorites have been reported, either, making this crater, which is identified from stratigraphy, an unusual, if not enigmatic, object. T. Smith and Hodge have performed SEM X-ray diffraction analysis of particles collected from the Veevers Crater, with interesting results. Considerable amounts of meteoritic material was recovered from the soil of the Henbury Group, including both impact composite glasses and ablation particles.

D. Brownlee, S. Love and L. Schramm have analyzed 100 μm to 1 mm extraterrestrial particles from the sea floor and from polar ice to study the elemental, isotopic, and mineralogical composition of the major asteroid compositions. Atmospheric entry calculations indicate that essentially all of the meteoroids in this size range that survive atmospheric entry have asteroidal origins. These large asteroidal particles reach the earth after Poynting-Robertson drag and impact the atmosphere at low velocity relative to cometary dust. The collected dust should be representative of dust generated in the asteroid belt but it is presently uncertain whether this is a representative sampling of the asteroids or whether there is a strong bias towards the families producing the IRAS dust bands. Laboratory analysis of the particles shows very clearly that the distribution of meteoroid types is quite different from the larger meteoroids that reach the Earth and survive as conventional meteorites. Ordinary chondrites, achondrites and irons are rare and the most common particle types are similar to carbon rich classes (CI and CM) of carbonaceous chondrites. Like CI and CM chondrites, many of the particles retain evidence of pre-terrestrial aqueous alteration indicating that ice must have been originally present in many of the asteroidal parent bodies. Space exposure lifetimes and aspects of these samples are being measured to study the dynamical evolution of solar system dust as is spirals towards the Sun.

Love, M. Laurance, S. Messenger and Brownlee continued analysis of meteoroid residue inside impact craters from the LDEF spacecraft. In rare cases unmelted residue was retained in craters in gold and aluminum. Analysis of this unmelted debris provides information on the mineralogical composition of meteoroids and records of irradiation history such as solar flare track density and implanted gas.

M. Lawler and Brownlee are completing analysis of mass spectrometer from the *Giotto* and *Vega* flybys of Comet Halley. The key emphasis at the present time is to determine the nature and fine scale distribution of silicates and carbon in cometary dust and to compare this spacecraft data from laboratory analysis of meteoritic samples.

The Department was pleased to learn that two members of our faculty have been honored via the naming of minor planets, in recognition of their contributions to planetary astronomy. Minor Planet Circulars 18139 and 18450 announce the naming of (4175) Billbaum = 1985 GX and (3259) Brownlee = 1984 SZ4, respectively.

b. Stars

G. Wallerstein and W. Spiesman have used the 6300 Å line to derive an upper limit to the oxygen abundance in two K subdwarfs with [Fe/H] ~ -1.5. They do not confirm the high O/Fe ratios found by Abbia and Rebolo for F-type subdwarfs of similar metallicity.

G. Gonzalez and Wallerstein have completed the analysis of ROA 24 in ω Cen from CTIO echelle spectra covering most of the spectrum from 3800 – 8800 Å. They find C, N and O to be enhanced, indicating that substantial amounts of 3-α processed material, some of which was subsequently CNO processed, have reached the surface of this post-AGB star. The s-process elements are enhanced, and Al is deficient relative to Fe.

In cooperation with V. V. Smith and K. Cunha (Texas), J. Brown and Wallerstein have analyzed O and Fe in 18 red giants in ω Cen from CCD echelle spectra. Over the range in metallicity from -1.0 to -2.0 dex, the [O/Fe] value remains constant near [O/Fe] = +0.4, as seen in most red giants in the field and in globulars of similar metallicity.

Wallerstein and Brown have obtained CCD echelle spectra of four stars with a range of CO indices in NGC 3201 to derive CNO abundances and $^{12}C/^{13}C$ ratios.

Wallerstein has begun to accumulate spectra of the Cepheids V1 and V29 in ω Cen, as well as the field Cepheid ST Pup. The data will be supplemented and analyzed by Gonzalez for his Ph.D. thesis.

Wallerstein has been following the symbiotic nova AS 296 (= FG Ser) which began an outburst in 1988. A proposal for observations with the ROSAT X-ray satellite has been accepted.

A. D. Vanture under the supervision of Wallerstein continues to analyze the abundance patterns in CH giants for his dissertation. Thus far the carbon isotope ratios have been derived. The isotope ratio found in eight CH stars ranges from >20 to near the equilibrium values set by the CN cycle ($\sim$ 3.5). Therefore, the carbon isotope

ratios in the CH stars have a pattern similar to Pop II field giants and globular cluster giants. Work is continuing on deriving the full CNO and heavy element abundances in the CH stars.

Under the supervision of Wallerstein, Gonzalez and F. Piche have completed a two year survey of the nearest stars using the Washington photometric system, in order to derive an accurate color-magnitude diagram for lower main sequence stars with a substantial range of metallicity.

E. Böhm-Vitense and J. Mena-Werth continue their studies of transition layer heating and emission. For giants, a close correlation between a steep decrease of the maximum $v \sin i$ and an increase in the nitrogen to carbon abundance ratio is found at $T_{eff} = 5400$ K, when the depth of the convection zone increases rapidly. This coincidence argues in favor of deep convective mixing as the origin for the decrease in $v \sin i$.

Mena-Werth and Böhm-Vitense continue to determine C and N abundances for cool stars of different luminosity classes. Böhm-Vitense started theoretical studies to better understand the temperature stratifications in transition layers.

In one of the first *Hubble Space Telescope* publications, B. Margon and S. Anderson, together with R. Downes (GSFC), R. Bohlin (STScI), and P. Jakobsen (ESA) reported Faint Object Camera images of the globular cluster M14, in an attempt to recover the quiescent counterpart of Nova Oph 1938. The $11 \times 11''$ frames easily resolve several hundred stars in modest exposures, implying that *HST* even in its current optical configuration will be unique for studies of very crowded fields at moderate ($B \sim 22$) limiting magnitudes. The candidate for the nova found from previous ground-based observations is resolved into at least six separate images, none with obviously peculiar colors. The situation is clearly more complex than had been appreciated from ground-based data, and further *HST* observations will be needed to unambiguously identify the nova.

J. Deeter and P. Boynton are continuing several collaborations with colleagues in Japan involving X-ray observations obtained with *Ginga*. Together with M. Scott, they are analyzing *Ginga* data on Her X-1 to test various models for the 35-day cycle in this binary X-ray system. In collaboration with S. Miyamoto and S. Kitamoto (Osaka U.), they are analyzing observations of Her X-1 obtained during a short high state in May 1990, with the goal of comparing cyclotron absorption features during short and main high states. This should provide an additional test of the free-precession model for the 35-day cycle.

Deeter and Boynton are analyzing *Ginga* observations of SMC X-1 to look for correlated fluctuations in neutron star angular acceleration and X-ray flux. In collaboration with S. Rappaport, A. Levine (MIT), and F. Nagase (ISAS), they have detected a secular decrease in the orbital period of SMC X-1 by combining all available pulse-timing data on this binary X-ray pulsar.

Deeter is collaborating with R. Manchester (ATNF) and Nagase to combine X-ray, optical and radio observations of PSR 0540-69, the young, Crab-like pulsar in the LMC. He and Nagase are also involved in a program to analyze the remaining *Ginga* data (1989–91) on PSR 0540-69. By combining these data with other pulse-timing results for this pulsar, they will be able to greatly extend the interval of coherent pulse-timing for this pulsar beyond the one year currently available.

With Scott, Boynton has just completed a study of quasi-periodicity that arises as an artifice from the application of standard analysis methods to data exhibiting red noise processes. They are preparing a paper in which these ideas are applied to a pulse timing study of the rotational behavior of the Crab pulsar using the extensive Jodrell Bank data on this source.

A. Phillips and Margon continued their analysis of spectra of NJL 5, the eclipsing blue straggler in ω Cen. The measured K-velocity of the A-star primary (24 km s^{-1}), along with the geometric properties determined from the light curve, implies a mass ratio $M_2/M_1 \sim 0.1$ and a comparable ratio for the radii; the existence of an *evolved* low-mass secondary thus demonstrates that at least one globular cluster blue straggler is a mass-transfer binary. They have also been able to extract a (very noisy) spectrum of the secondary, which will allow constraints on the masses of both stars.

P. Szkody and S. Howell (PSI) are continuing the study of a selected group of 90 cataclysmic variables at high galactic latitudes, to compare with the properties of those located in the plane of the Milky Way. The past year concentrated on low resolution spectroscopy for 32 of the sample objects. Using the secondary detections obtained from these spectra as well as available literature values enabled distance and absolute magnitude determinations for 12 high latitude dwarf novae. Of these, 3 (25%) have absolute magnitudes several magnitudes fainter than values for low latitude systems. These 3 systems are also among the ones with the largest outburst amplitudes. However, further data are needed to reach a definitive conclusion about the connection of outburst amplitude with evolutionary history or low mass transfer rate.

A simultaneous ultraviolet (*IUE*) and optical (photometry and spectroscopy) study of the peculiar cataclysmic variable S193 during a high mass transfer state was carried out for 2 nights by Szkody, P. Garnavich, A. Larson (U. Vic.) and R. Wagner (OSU). Although large changes were apparent in the He I λ4471 line profile and flux, and in the *IUE* spectrum from previous spectra during the low state, there was little correlation or periodicity evident in the multi-wavelength data. Thus, the high mass transfer state appears more similar to a dwarf nova in outburst than to a DQ Her system.

Szkody, Garnavich and M. Mateo (OCIW) obtained time-resolved spectra of U Gem in the 8100–8800 Å region which show the presence of a sharp component in the Ca line near phase 0.5, similar to a previous study of YY Dra, and indicative of X-ray heating of the secondary star. Although the orbital periods of the 2 systems are very similar, the observed X-ray luminosity of YY Dra is an order of magnitude larger than for U Gem, but the equivalent width of the Ca sharp line is larger in U Gem. This result implies large differences in accretion rates and/or disk geometries in the two systems. A survey of other dwarf novae with known X-ray fluxes and observable secondaries is planned.

Szkody, R. Williams (CTIO), Margon, Howell and Mateo completed a study of the unusual dwarf nova TT Crt (FSV 1132–11), which reveals the orbital period is long (438 min) and detects the secondary (a K5–M0 star). The remarkably large amplitude of the ellipsoidal variation from the secondary star which dominates the optical light curve indicates a high inclination (50–65°) and a massive white dwarf ($> 0.8\ M_\odot$). While the spectroscopic velocity solution is consistent with these parameters, the explanation of the color dependence of the light curves may require two extra emission components in the accretion disk.

E. Peterson has calculated a series of cool non-DA white dwarf atmospheres in the temperature range $4000\ \mathrm{K} \lesssim T_{eff} \lesssim 7000\ \mathrm{K}$, using the Hummer-Mihalas equation of state and an opacity calculation which is compatible with the Hummer-Mihalas occupation numbers. He is also specifically studying the pressure ionization of metals in these atmospheres.

c. Interstellar Material

Wallerstein and K. K. Gilroy have completed an analysis of interstellar Ti II, Ca I, CH and CH^+ from CCD

spectra of stars behind and within the Vela Remnant and η Car Nebula. Several of the above species are unexpectedly strong due to shock excitation and the evaporation of grains. Most surprising is the discovery of high velocity Ca I in several η Car stars.

B. Balick, with A. Frank, and V. Icke and G. Mellema (Leiden), are completing development of numerical 2-dimensional hydrodynamical code with realistic radiative energy loss for use in synthesizing the properties of planetary nebulae. Models made with radiationless 2-D codes show that one can explain most of the morphological features of planetaries ranging from the extreme bipolars (such as the Saturn Nebula) to diffuse double-cavity nebulae (such as the Owl Nebula).

Observations by Balick, Gonzalez, and Frank with the Manastash Ridge Observatory (MRO) CCD (complemented by 4m prime-focus CCD images by G. Jacoby, NOAO) have allowed them to probe the structure of the very faint extended halos of planetaries. These studies are motivated by the allegations that the halos are very old pulses of mass ejected by AGB stars. These studies of the shapes of halos are being used to constrain the ejection history of the mass.

In the past year spectroscopic observations by Balick with Y. Terzian (Cornell) and M. Rugers have been completed of the peculiar low-ionization knots seen in pairs on opposite sides of PN nuclei. These knots are almost invariably embedded deeply inside gas of much higher ionization, and move through this gas at about 40 km s^{-1}, sometimes leaving a seemingly shock-excited bow and wake.

Observations were also made of the H- and He-depleted "fast-moving knots" at the outer perimeter of Cas A with Terzian and Rugers. The Doppler shifts of the knots (which must be caused by nonradial motions) are as large as their proper motions: 6000 km s^{-1}. Either the knots are not ejecta originating at the explosion site, or some unknown mechanism seems to deflect them as they reach the edge of the remnant. Further observations are planned for next year.

Balick and three undergraduates, K. Sabo, C. Dracobly, and B. Welch, have been using MRO to conduct an optical survey of Minkowski objects with the goal of obtaining accurate positions, Hα fluxes, and morphology information. The objectives are nearly complete aside from the flux calibrations, and a catalogue will be prepared for submission this year.

K. H. Böhm and A. Noriega-Crespo, in collaboration with J. Solf (MPI Heidelberg) and A. Raga (CITA, now U. Manchester), have carried out a detailed study of the two dimensional distribution of the radial velocity and the velocity dispersion in HH1. The results are based on a dense coverage of the object by long slit spectra obtained by Solf. While many of the earlier observations (which were partially restricted to the axis of the object) have been explained well by bow shock and other hydrodynamic models, the interpretation of the two dimensional velocity information leads to difficulties which are not yet explained by any of the existing models, indicating that some important aspects are still missing in the present models of the working surfaces of jets.

Very recently Böhm and Solf have carried out a similar study of the very complex object HH2, using long slit coudé and double spectrograph spectra. As in the case of HH1, the axis of the motion also lies in the plane of the sky. Interestingly only the brightest condensations show a maximum in the velocity dispersion in or near the intensity maximum. Surprisingly the fainter condensations show minima in the velocity dispersion and in the excitation at their center relative to the diffuse environment. Only the electron density shows maxima at the centers of faint condensations. In the highest excitation condensation HH2A′, there are drastic differences between the velocity dispersions in different lines, with the FWHM being almost four times larger for [O III] λ5007 than for [S II] λ6716 at the center of the condensation. It is well known that this type of result is not compatible with the often used "1.5 dimensional" bow shock model.

Böhm and Solf have completed and published their study of direct and dust scattered line emission in the Herbig-Haro complex HH1/HH2 which, among other results, clearly showed that the line profiles of the HH1/2 jet are composed of a core which is formed locally and an extended blue wing which is due to dust scattering.

Noriega-Crespo and Böhm have, in collaboration with N. Calvet (CIDA, Venezuela), completed and published their study of the theoretical profiles of dust scattered lines of HH objects.

Böhm, Noriega-Crespo, Solf and Brugel (Colorado) have completed their study of the *IUE* (SWP) spectrum of the Herbig-Haro object HH24 (which shows in the UV only a detectable continuous spectrum, without emission lines) and its spatial variation.

Noriega-Crespo, in collaboration with Garnavich and P. Green, has finished a wide field camera imaging study of new Herbig-Haro objects recently discovered in the L1551 star forming region. The [S II] $\lambda\lambda$6716, 6731 and Hα images of the new condensations confirm that the emission is shock excited. Some new distant condensations in the region are presently under study.

Noriega-Crespo has completed, in collaboration with Frank and Balick, a theoretical study on the hydrodynamic cooling effects in ionized stellar flows and their application to planetary nebulae.

d. The Galaxy

G. Lake and K. Ashman (STScI) are examining several problems of the formation and chemical evolution of both globular clusters and the field stars of the Milky Way. Observations of the radial velocity ellipsoids of the clusters are used to constrain their integrated mass loss. The radial distributions and luminosity functions of both direct and retrograde clusters have been used to gauge the importance of dynamical friction, evaporation, and disk shocking in shaping the present day properties of clusters. While these processes clearly occur, they have not reshaped the luminosity function of the clusters. Current theories of the formation of globular clusters have been similarly confronted with observations and found to be seriously flawed. The standard argument against self-enrichment of clusters (narrowness of the metallicity distribution) is found to apply equally to field stars in both the halo and disk. A new paradigm for chemical enrichment has been proposed.

Green, in collaboration with Margon and Anderson, completed a CCD survey for faint halo carbon stars, using an intermediate-band color system. About 55 deg^2 are covered to magnitudes as faint as $V \sim 18$. Although followup with slit spectra is still in progress, very low surface densities are already indicated. An unexpected surprise in the course of the project was the discovery by Green, Margon, and D. J. MacConnell (CSC/STScI) of three *dwarf* carbon stars, recognized by their high proper motions. Previously only one such object, G77-61, was known. As all four of these stars are within a few hundred pc of the Sun, the space density of carbon dwarfs may actually be comparable to or even in excess of the better known carbon giants. Final analysis of the CCD survey data should be useful in constraining the numbers of both types of stars.

Garnavich studied the clustering properties of a sample of stars from the Space Telescope Guide Star

Catalog (GSC). The region analyzed lies within 30° of the NGP and covers 2000 deg^2 of sky. He identified many systematic errors in the GSC and attempted to account for image misclassifications and poorly defined resolution limits. The corrected stellar correlation function from the GSC was found to be consistent with a wide binary separation cutoff near 0.1 pc. The cutoff may be a result of the dissolution of a poor stellar cluster at the NGP, or a mechanism similar to that working in the Oort comet cloud could inhibit the formation of wide binary stars with separations greater than 0.1 pc.

e. External Galaxies and QSOs

Hodge continued his study of the star-formation histories of galaxies. For a sample of nearby irregular-type galaxies, star formation lifetimes were found to range from a short 0.7 Gyr for the starburst galaxy NGC 1569 to 180 Gyr for the relatively quiet galaxy DDO 187. With N. Strobel and R. Kennicutt (U. Ariz.), he published an atlas and analysis of the H II regions in seven dwarf irregular galaxies in and near the Local Group. Luminosity functions and size distributions for the H II regions were derived and compared to available data for spiral galaxies and with theoretical models.

B. Miller, working with Hodge, analyzed the spiral structure of the barred Virgo Cluster galaxy NGC 4303. Using BVR and Hα CCD frames obtained at MRO, as well as older photographic data obtained by Hodge at Lick and KPNO, he examined the geometrical and physical morphology of the arms and the star-formation activity as a function of position in and out of the bar and in and out of the arms.

E. Wilcots and Hodge carried out a multi-wavelength study of several star-formation regions in the two Magellanic Clouds; the data included UV and optical spectroscopy, as well as optical photometry of the stars and gas, neutral hydrogen mapping and radio observations of continuum emission. The *IUE*, various CTIO telescopes, the Parkes radio telescope and the Australia Telescope were all employed in this study of normal-sized regions of star formation in galaxies where conditions are different from those in the solar neighborhood.

Hodge and K. Krienke (Seattle Pacific U.) carried out a study of the spiral arms of NGC 2403, using wide-band high-resolution photographs, Hα images, and CCD images taken at MRO by Miller.

Hodge and M. Fich (U. Waterloo) observed the M31 elliptical galaxy companion NGC 205 with the JCMT at 1.1 mm, concluding from the observed continuum flux, combined with IRAS and optical data, that there is approximately 2000 $M_\odot$ of dust in the galaxy at a temperature of approximately 23 K.

Hodge, working with P. Battinelli (Astron. Obs. Rome) and R. Capuzzo-Dolcetta (U. Rome), explored the problem of objectively identifying OB associations in external galaxies, especially those for which stellar resolution is not possible. A combination of principal component analysis and cluster analysis has been developed for the purpose and has been applied to KPNO 4m CCD images of the Sc galaxy NGC 2403.

Sullivan, together with C. Balkowski, V. Cayatte (Meudon), P. Amram, and M. Marcelin (Marseilles), finished the CFHT observations of Hα rotation curves in cluster spiral galaxies. About 35 galaxies in 7 clusters have been observed and results from the first 20 are now in press. A small effect of the cluster environment on the gradients in the curves is probably present, but nothing is detected of the magnitude reported by V. Rubin.

Phillips is continuing his study of massive star formation in barred spiral galaxies, using continuum-subtracted Hα images of 15 barred spirals to identify star formation sites, and to construct Hα luminosity functions for comparison with non-barred spirals. The goal is to study the effects of a well-understood non-axisymmetric potential on local and global star formation properties. Observations and data reduction are complete and analysis fully underway. The bars are seen to have little or no influence on star formation at radii much beyond the bar, but strongly influence the distribution and properties of H II regions within the bar radius: there star formation properties are seen to show wide variations through the sample, strongly correlated with Hubble type.

Lake and Smith are continuing a program of observing and modeling the distribution of dark matter in galaxies. The latest result has been the puzzling inconsistency of the cold dark matter theory with both the observed trend of phase density of dark matter with luminosity and the radial profile of dark matter in galaxies. While "hot" dark matter has gross problems with the formation of galaxies, it predicts the observed relationship of phase density with luminosity.

Green, Anderson, and M. Ward (Oxford) completed a study of the far-infrared and X-ray properties of a large sample of active and normal galaxies, using data from IRAS and Einstein. They found that galaxies with soft X-ray to infrared flux ratios $\gtrsim 0.01$ are almost certain to show broad-line optical emission. In addition, they found a significant correlation between X-ray and IR luminosities for galaxies of many types, but with a strong offset separating broad-line from normal and narrow-line galaxies. Using recent IRAS infrared luminosity functions with their X-ray/IR correlations, they estimate that IR-emitting galaxies contribute $\sim 5-25\%$ to the cosmic X-ray background at a few keV.

Margon and Phillips, together with R. Ciardullo (PSU) and Jacoby, identified a near-infrared counterpart to the highly variable, unresolved galactic plane radio source GT 0116+622. This source is of particular interest as it has been previously suggested to be the counterpart of the γ-ray source Cas γ-1. Their near-infrared and red images detect a faint ($R\sim23$), spatially extended (3″ FWHM) very red object coincident with the radio position. The data are consistent with an interpretation of GT 0116+622 as a unusually variable, obscured active galaxy at a distance of several hundred Mpc, although more exotic, and in particular galactic, interpretations cannot yet be ruled out. If the object is extragalactic, the previously suggested identification with the γ-ray source would seem unlikely.

With J. Lowenthal (U. Ariz.) and others, Hogan discovered a "Lyα Galaxy" in emission near a previously known damped Lyα absorber along the line of sight to the QSO PHL 957. The object was found as part of a survey searching for such objects and is the first of its kind to survive scrutiny. It is the highest redshift galaxy not selected on the basis of its emission, and the most direct evidence to date for the correlation of damped absorbers with protogalaxies.

Anderson, in collaboration with F. Chaffee, Jr. and C. Foltz (MMT), P. Francis and P. Hewett (IoA), G. MacAlpine (U. Mich.), and S. Morris and R. Weymann (OCIW), completed initial work on the Large, Bright Quasar Survey (LBQS). The LBQS QSOs were quantitatively selected via computer algorithms from UK Schmidt objective prism (and direct) plates, digitized and processed through the APM at IoA. Spectroscopic and photometric follow-up have been completed. The LBQS sample includes more than 1000 confirmed QSOs, most brighter than $B = 18.8$ and with redshifts $0.2 < z < 3.3$.

In the first scientific result published with the *HST* Faint Object Spectrograph, Margon collaborated with E. Beaver (UCSD) *et al.* in UV spectroscopy of UM 675, a $z = 2.1$ QSO. Even in the relatively brief exposure, light was detected down to 520 Å in the rest frame of the object. The data have been used to set limits to He I emission, the

He I Gunn-Peterson effect at $z = 2$, and Lyα absorption at $z \sim 0.5$, as well as to the examine the continuum at this previously hidden rest-frame wavelength.

Anderson, in collaboration with D. Koo (UCSC), S. Majewski (OCIW), P. Schechter (MIT), and R. Windhorst (ASU), has continued a program to establish a sample of very faint ($m < 24$), optically-selected QSOs. A number of candidates with magnitudes in the range $m = 22.5 - 24$ have been selected from deep multicolor Four-Shooter CCD frames taken with the Palomar 5m.

Anderson, in collaboration with R. Windhorst (ASU), D. Burstein (ASU), R. Griffiths (STScI), D. Koo (UCSC), T. Maccacaro (Milano), D. Mathis, and L. Neuschaefer (ASU), is participating in a ROSAT deep X-ray survey of the selected area Lynx.3A. Deep optical multicolor CCD frames and radio maps in Lynx.3A have already been taken and reduced; these should yield optical and/or radio identifications for the many faint X-ray sources detected in the deep ROSAT image.

X. Wu and Anderson completed their study of the contribution of faint QSOs ($B < 22.5$), and other discrete sources, to the cosmic X-ray background (XRB). Their investigation used a new approach that sensitively tests for a positional correlation between positive fluctuations in the XRB and the locations of the faint optically-selected QSOs. The X-ray data are from archived Einstein IPC images which cover the region in SA68.2 surveyed optically for faint QSOs by Shields *et al.* Wu and Anderson find that discrete sources contribute at least 30% of the XRB at a few keV (with a formal uncertainty of only $\pm 5\%$).

With M. Fukugita (Kyoto), Hogan reviewed the empirical foundation of the supernova Hubble diagram in the light of new distance measures to several Virgo cluster galaxies. The evidence seems to favor a higher Hubble constant than expected on the basis of *a priori* modelling of the supernova phenomenon, indicating that these models may have overestimated the peak blue brightness by a modest factor.

f. Cosmology

C. Hogan has continued his theoretical studies of radiation-driven instabilities and their possible role in the generation of cosmic structure. An analysis of the nonlinear effects associated with the "mock gravity" instability led him to conclude that it is a self-organizing dissipative process, leading to the formation of structures whose statistical properties are largely independent of initial conditions. With J. Woods (UW Physics) he completed a study confirming this prediction with simple one-dimensional simulations.

Hogan, J.R. Bond (CITA) and B. J. Carr (London) completed their study of cosmic backgrounds from primeval dust, using the current data from the COBE satellite to constrain energy release at high redshift. The "medieval" universe was shown to have been remarkably quiescent. Among the many excluded scenarios are those in which mock gravity plays a prominent role in large scale structure. Many forms of stellar dark matter are excluded, as are explosive scenarios for galaxy formation and many forms of decaying particles. Predictions for COBE and future instruments were made, both the forms of mean spectral distortions and the spectral anisotropy.

Hogan discovered a new instability, dubbed the "Doppler Instability", which can occur in neutral gas at arbitrarily low density and on arbitrarily large scales. The instability is caused by a radiation field with a distribution function increasing with frequency near an atomic resonance, such as Lyα. Hogan studied the linear theory of perturbations in a nearly uniform medium of radiation and scattering gas, preserving the frequency dependence of the distribution function. The feedback and saturation of the instability were studied, and the final form of the fluctuation spectrum estimated. Predictions were made for the cosmic infrared background for models in which large scale structure is generated by this instability.

Hogan also discovered another new instability, which occurs at the epoch of cosmic recombination. Although it is only important on small scales (stellar masses), it occurs in a minimal big bang model with no additional sources of energy. A lump of gas expanding faster than average releases its Lyα photons early, increasing its pressure and leading to even faster runaway expansion. Although further analysis is needed to determine the range of mean baryon densities for which this occurs, the effect is likely to strongly influence the formation of the first stars.

Hogan gave invited reviews at the Texas/ESO/CERN symposium in Brighton and the IUPAP conference in Tokyo on primordial nucleosynthesis with fluctuations and on cosmic instabilities.

g. Miscellaneous

Sullivan and Lake have joined the Investigators Working Group of NASA's Search for Extraterrestrial Intelligence Microwave Observing Project. Primary effort is being devoted to optimizing overall strategy for the targeted search of nearby stars and the all-sky survey, as well as to astrophysical spinoff from the high resolution (30 Hz), broadband (1–10 GHz) sky survey. It has often been argued that the first detections will be superluminous civilizations in other galaxies. However, an implicit assumption in the proposed existence of such civilizations is that the evolutionary time is short. Using the V/V_{max} statistic, Lake has shown that for evolutionary times as short as 10–100 million years, the survey volume collapses to the Galaxy.

Sullivan continued working on his long-term project on the history of radio astronomy. He organized sessions on history of twentieth century physics and astronomy at meetings of both the History of Science Society and the AAS Historical Astronomy Division, speaking on his analysis of the relationships between early optical and radio astronomers. He also wrote a paper on the origins in England and Australia of various interferometric techniques, for the Proc. of the IAU Colloquium on "Radio Interferometry".

The Department hosted the 178th meeting of the American Astronomical Society on May 26–30, 1991 at the Westin Hotel in Seattle. The AAS had not previously visited Seattle for almost two decades. The Local Organizing Committee consisted of Margon (Chair), Wallerstein, and Krienke. Over 900 participants registered, an unexpectedly large number for a summer meeting. Scientific highlights included numerous results from *Astro*, *HST*, and *GRO*.

III. INSTRUMENTATION

Work continues on the commissioning of the 3.5m telescope of the Astrophysical Research Consortium (ARC), at Apache Point, New Mexico. The effort at the UW is lead by Balick, E. Mannery, W. Siegmund, C. Hull, and R. Owen. While the primary mirror completes final polishing, 1.8m temporary optics are in the telescope, and the facility is in use almost every clear night for checkout of the telescope, software, and instrumentation. Initial results on the pointing and tracking of the telescope are extremely gratifying.

Margon continues as Chair of the Board of Governors of ARC. The Consortium is in the early stages of planning for a 2.5m redshift survey telescope, also to be located at Apache Point. Preliminary engineering design work is underway at the UW by Siegmund, Mannery, Hull, and

Owen. ARC is also considering placement of one or more small telescopes at the site.

Siegmund continues his program of examining the effect of telescope enclosure design on airflow through the building. In the past year, studies were accomplished for the NOAO 8m Gemini telescopes, as well as the Magellan project.

P. Waddell, Hodge and Szkody are developing an Undergraduate Instruction Laboratory which will provide undergraduates with experience in modern data acquisition and reduction. Four SUN workstations have been purchased as well as a thermoelectrically cooled Photometrics CCD. The CCD will be used for students to gain familiarity with detectors in a lab environment. One SUN is being installed at MRO to operate a nitrogen-cooled CCD on the 0.8m telescope. The other 3 SUNS remain on campus for students to learn IRAF data reduction routines, and other image processing software.

Balick is collaborating with W. Kimura of STI Optronics (Bellevue, WA) to develop a safe, effective cleaning method for large astronomical mirrors. A proposal for funding was submitted to the Instrumentation section of the NSF Astronomy Division. Meanwhile, a set of microscope and SEM slides has been aluminized for distribution to major observatories in Arizona, Hawaii, and Chile for dust collection and later test cleaning.

Margon and Anderson continue their work on the *HST* Faint Object Spectrograph team. The instrument itself is working well, with the exception of a few fairly minor anomalies; the most significant is probably reduced throughput for a short stretch of bandpass near Lyα. Due to the complexities of the STScI scheduling process, most of the team's guaranteed-time observations have yet to be scheduled for observation. It is anticipated the pace of observations will increase considerably in the next year.

Boynton and Rugers have been studying various statistical strategies for the detection of astrophysical point sources of TeV neutrinos using the Deep Under Water Muon And Neutrino Detector (DUMAND II) now under construction. Of particular interest is the optimization of detection probability through the choice of detector design parameters such as the energy threshold for neutrino induced muons and the celestial angular resolution obtained from muon track reconstruction.

Bruce Margon
Chairman