The Ohio State University

Astronomy Department

Columbus, Ohio 43210

This annual report covers the period 2000 September through 2001 August.

1 PERSONNEL

During the period covered by this report, the regular academic staff of the Department of Astronomy included Richard Boyd, Darren DePoy, Jay Frogel, Andrew Gould, Eric Herbst, Jordi Miralda-Escudé, Gerald Newsom, Patrick Osmer (chairman), Bradley Peterson, Marc Pinsonneault, Richard Pogge, Anil Pradhan, Barbara Ryden, Robert Scherrer, Kristen Sellgren, Gary Steigman, Donald Terndrup, Terrance Walker, David Weinberg, and Robert Wing. Since March 2001, Frogel has been on leave at the Lawrence Berkeley Laboratory, where he is a Visiting Senior Research Scientist in the Physics Division.

Michele Kaufman and Smita Mathur held appointments as Research Scientists, and David Ennis and Eric Monier were lecturers. Sultana Nahar was a senior research associate. Emeritus members of the Astronomy Department are Eugene Capriotti, George Collins II, Stanley Czyzak, Geoffrey Keller, and William Protheroe.

The staff of the Imaging Sciences Laboratory (ISL) included Bruce Atwood, Ralph Belville, David Brewer, Paul Byard, Jerry Mason, Thomas O'Brien, Daniel Pappalardo, David Steinbrecher, and Edward Teiga. Mark Derwent has joined the ISL as a mechanical engineer. Michael Savage was manager of the Astronomy Department computer resources.

In Tucson, AZ, Mark Wagner held the position of Research Scientist, while Ray Bertram was Research Associate. Wagner and Bertram are assigned full-time to work on the Large Binocular Telescope (LBT) project. Wagner is Instrumentation Scientist for the LBT, coordinating the instrumentation efforts of the LBT partners and developing instrument support on the mountain.

Postdoctoral researchers in Astronomy during part or all of this period included James Bullock, Stefan Collier, Paul Eskridge, David Graff, Andrey Kravtsov (Hubble Fellow), Eric Monier, and Marianne Vestergaard (Columbus Fellow).

Graduate students in the Astronomy Department during the academic year included Khairul Alam, Jin An, Nikolay Andronov, Andreas Berlind, Christopher Burke, Julio Chanamé, Guo-Xin Chen, Alberto Conti, Franck Delahaye, Dale Fields, Susan Kassin, Jennifer Marshall, Christopher Onken, James Pizagno, Patrizia Romano, Samir Salim, Adam Steed, Andrew Stephens, Jeremy Tinker, and Zheng Zheng. Justin Oelgoetz is an OSU Chemical Physics graduate student working on his Ph.D. thesis with Pradhan. Jennifer Marshall was the first recipient of the David G. Price Fellowship in Astronomical Instrumentation, endowed by OSU alumnus David Price to foster the training of a new generation of instrument builders in astronomy.

Graduate students arriving in the summer of 2001 were Juna Kollmeier, Grant Newsham, Josh Pepper, and Rik Williams.

Students completing their Ph.D. were Berlind (now at U. Chicago), Conti (now at U. Pittsburgh), and Stephens (now at Princeton/Universidad Catolica).

2 TELESCOPES AND INSTRUMENTATION

OSU has a one-quarter share of the observing time on the 2.4m and 1.3m telescopes of MDM Observatory on Kitt Peak. The other MDM partners are Dartmouth University, Columbia University, and the University of Michigan. OSU is also a partner in and will have one sixth of the observing time on the Large Binocular Telescope (LBT), which is under construction at the Mt. Graham International Observatory in Arizona. Other partners in the project are the University of Arizona, astronomical consortia in Italy and Germany, and the Research Corporation.

The LBT, with twin 8.4m mirrors, will be the world's largest telescope on a single mount and will have a 23m baseline for interferometric observations. During the last year, polishing was begun on the first primary mirror, and the telescope structure was assembled at the Ansaldo-Camozzi plant in Milan. The exterior and interior finishing work on the enclosure on Mt. Graham is nearly complete, and plans are being made for the transportation of the telescope components to the U.S. Work continued on the aluminizing system for the telescope, for which the department is largely responsible. Initial tests of the large vacuum system went well, as did tests of some prototypes. The aluminizing bell jar and dummy mirror cell will be shipped to Columbus, where ISL staff will install the equipment needed for the aluminizing system. First light for the LBT is currently scheduled for 2004.

The project to construct a multi-object double spectrograph (MODS) for the LBT is progressing. The project passed its Preliminary Design Review in May 2001 with flying colors and is now proceeding into construction. The optics design is complete, and contracts are being negotiated for optics fabrication. A number of prototypes of complex components (for instance, the grating turret and corrector lens cells) have been produced. Prototypes of the grating tilt mechanism have been successfully tested. Barring unforeseen difficulties, the Phase 1 MODS instrument (a single blue-channel spectrometer) will be delivered to the LBT in time for mirror 1 first light. Details on MODS progress are available at http://www.astronomy.ohio-state.edu/LBT/MODS.

Pogge configured a small CCD camera for the Crimean Astrophysical Observatory. The system included an Apogee AP7p CCD, control computer, and power management system, with documentation. The camera will be used on the CrAO 0.6m telescope for photometric monitoring of active galactic nuclei and variable stars.

We also continued to support and maintain existing instruments, including OSIRIS and ANDICAM at Cerro Tololo Inter-American Observatory in Chile, DANDICAM at the South African Astronomical Observatory in South Africa, and TIFKAM and CCDS at MDM Observatory in Arizona.

3 SOLAR SYSTEM & PLANETS

Wagner, in collaboration with R. Millis, M. Buie, and L. Wasserman (Lowell), and J. Elliot and S. Kern (MIT), is continuing a project to detect faint Kuiper Belt Objects (KBOs), using the MOSAIC CCD cameras at the Mayall and Blanco 4m telescopes. An extension of this investigation, called the Deep Ecliptic Survey and including Co-I's E. Chiang (UCB) and D. Trilling (U. Penn.), was recently approved as an NOAO Survey Program. The program seeks to undertake a deep survey of the ecliptic to learn the dimensions, content, and dynamical characteristics of the Kuiper Belt. The product of this survey will be a publicly accessible database of ~ 500 new KBOs, with well-understood and readily quantified biases. The initial results of the survey, using observations obtained between 1998 October and 2000 February, have been accepted for publication. Sixty-nine KBOs and Centaurs with $R = 20.6-24$ mag were discovered. The preliminary results suggest that the relative frequency of objects as a function of ecliptic longitude is not symmetric about the longitude of Neptune. The observed distribution of orbital inclinations suggests that the true distribution is similar to that of short-period comets. In 2000 July, the team announced the discovery of the intrinsically brightest KBO yet found. 2001 KX76 was discovered on images obtained by Elliot and Wasserman with the Blanco 4m. Assuming an albedo of $4-7$ percent, 2001 KX76 would have a diameter of ~ 1100 km, comparable to Pluto's moon Charon. Further observations, including thermal IR observations to determine its albedo and size, are planned for next year.

Miralda-Escudé investigated the possibility of detecting small perturbations to the orbit of an extrasolar planet with observed transits. Such perturbations might be caused by the quadrupole moment of the star or by the gravitational influence of a second planet with a mass as low as an Earth mass.

Pinsonneault, Depoy, and M. Coffee studied the question of whether the high metal abundances in stars with planets are primordial or caused by the infall of rocky material. They found that infall at a rate sufficient to affect the bulk metal abundance would produce strong trends in metallicity with effective temperature; such trends are not seen in the data. This does not preclude infall, but does indicate that the stars were born with high metal abundances.

4 STARS AND BINARIES

Wing has started observations with a new set of 6 interference filters in the near infrared ($0.71-1.06$ μm). Narrow-band photometry at continuum points and wavelengths sensitive to the presence of TiO and CN molecules is extracted from CCD images obtained at the MDM Observatory. Initial observations have concentrated on the establishment of a new set of standard stars and determining the transformation to Wing's well-established eight-color system of classification photometry. Tests have shown that dwarfs, giants, and supergiants of type M are easily distinguished on the basis of their CN strengths. As a first application of the new filters, Wing is obtaining two-dimensional classifications for red stars in the northern Milky Way, suspected of being reddened late-type supergiants in the Case objective-prism surveys conducted by J. J. Nassau, V. M. Blanco, and colleagues more than 40 years ago. Most of these stars have not been studied – or even confirmed as supergiants – since the original survey work. However, since distances can be determined for M stars with two-dimensional (TiO, CN) classifications, these stars have potential for adding to our knowledge of the arrangement of the spiral arms of the Galaxy. Wing is also attempting to identify fainter and more distant late-type supergiants through deep V, I imaging and follow-up narrow-band photometry of red candidates.

Pinsonneault and Terndrup, in collaboration with A. Sills, R. Jeffries (Keele), and J. Stauffer (IPAC), have been obtaining new data on stellar rotation rates ($v \sin i$) in young and intermediate-age stellar clusters. Their first effort was in NGC 2516, a cluster about as old as the Pleiades (120 Myr), but more metal-poor by ~ 0.3 dex. They have also obtained an extensive sample of stars in the intermediate-age clusters NGC 752 and NGC 2420, prototype clusters for the calibration of convective overshoot in stellar evolutionary models, and in NGC 5822 (also in collaboration with S. Hawley, MSU). When complete, these data will provide the first look at the effects of metallicity on angular momentum evolution, and will yield important calibrating data for the production of giant branch models which properly treat rotationally induced mixing and dredgeup.

With new NSF funding, R. Peterson (Lick Obs.) and Terndrup are undertaking an extensive survey to find and characterize hot horizontal-branch stars in the nuclear bulge of our Galaxy. Such stars have been suggested as the source for the copious ultraviolet emission from ellipticals and other spiral bulges, but there do not yet exist significant samples for study in bulge-like environments. During Summer 2001, they obtained extremely deep imaging with the MOSAIC camera on the Blanco 4m telescope, revealing the presence of a large number of UV-bright horizontal branch stars down to $B \approx 22$. They also had a successful run with the Two-degree Field instrument at the Anglo-Australian

Telescope in July, obtaining metallicities and kinematics for cooler ($T \leq 12,000$ K) horizontal-branch stars. This work is in collaboration with A. Walker (CTIO), E. Sadler (U. Sydney), and E. Green (Arizona).

Andronov, with Pinsonneault and Depoy, examined the implications for cataclysmic variables (CVs) of recent work on the angular momentum evolution of open cluster stars. They found that angular momentum loss prescriptions previously used for CVs are much larger than the empirical values inferred from open cluster stars. Furthermore, previous theoretical explanations of the 2–3 hour period gap relied on the absence of magnetic braking in fully convective stars; this is directly contradicted by open cluster data. This work opens the possibility that the evolutionary state of the secondary, rather than features in the angular momentum loss rate, is responsible for the bimodal CV period distribution.

Tinker, with Pinsonneault and Terndrup, investigated the role of accretion disks in regulating the angular momentum evolution of low mass stars. Angular momentum loss from a magnetized stellar wind in low mass stars can be constrained by comparing data from open clusters of different ages. The pre-main-sequence rotation measurements, it is found, cannot be evolved into the open cluster distribution without an angular momentum loss mechanism in addition to stellar winds. The pre-main-sequence and open cluster distributions are consistent if disk-locking with a distribution of accretion disk lifetimes inferred from infrared measurements is included.

Pinsonneault, Steigman, Walker, and V. Narayanan (Princeton) have used observations of Pop I stars to normalize the rotational mixing of lithium from stellar surfaces, permitting limits to be set on lithium mixing in the Pop II stars used to infer primordial lithium abundance. This work has recently been expanded to include a comparison with a new, independent data set. It was found that the BBN-predicted lithium abundance corresponding to the observed deuterium abundance requires halo star lithium depletion in an amount consistent with their models.

Wagner, in collaboration with C. Foltz (MMTO), S. Starrfield (ASU), T. Shahbaz and J. Casares (IAC, Tenerife), P. Charles (Southampton), and P. Hewett (IOA, Cambridge), measured the mass function and binary orbital parameters of the high-latitude soft X-ray transient XTE J1118+480. Spectroscopic data yielded a mass function of 6.1 $M_\odot$, giving a firm lower limit on the mass of the compact object, strongly implying it is a black hole. Modeling of the photometric light curve gives a large mass ratio ($\simeq 20$) and a high orbital inclination ($\simeq 81°$). The combined fits yield a black hole mass of 6.0-7.7 $M_\odot$ for plausible secondary star masses. The object is estimated to lie 1.7 kpc above the Galactic plane, indicating that J1118+480 is the first firmly identified black hole X-ray system in the Galactic halo.

Wagner, C. Zurita, (IAC, Tenerife), Casares, Shahbaz, Foltz, Charles, Starrfield, R. Hynes (Southampton), P. Rodríguez-Gil (IAC, Tenerife), and G. Schwarz and E. Ryan (Arizona) continued the analysis of photometry of XTE J1118+480. A time series analysis of the photometric data yields a period 0.3% longer than the spectroscopic orbital period, implying a disk precession period ~ 52 days. Doppler images of the Hα line show a bow-shaped brightness distribution moving in orbital phase. The Hα line profiles exhibit velocity variations consistent with a period of $P_{\rm prec}/2$ and a semi-amplitude of $460\,{\rm km\,s^{-1}}$. This is believed to be the first spectroscopic evidence for an eccentric precessing accretion disk.

Wagner, Shahbaz, Casares, Charles, Zurita, G. Dubus (Caltech), and Ryan analyzed an extensive set of optical light curves of the soft X-ray transient XTE J2123-058 obtained during its 1998 outburst, decay, and quiescence. Combining the results of a light curve model with the measured mass function gives masses of 1.30 and 0.46 $M_\odot$ for the neutron star and secondary star respectively. The quiescent photometry requires contributions from an X-ray irradiated secondary star and an accretion disk bulge (occurring where the gas stream impacts the accretion disk).

Wagner, Starrfield, and J. Drake (CfA), on behalf of a larger collaboration, analyzed Chandra observations of the classical nova V1494 Aql. The data revealed an enormous flare of X-rays that lasted for about 15 minutes; such an outburst has not been seen previously in a classical nova. In addition, time series analysis of the data showed the presence of a pulsation with a period of about 2523 seconds. Several other statistically significant periods are present, suggesting that the light curve is composed of a spectrum of discrete periods similar to that observed from the pulsating hot central stars of planetary nebulae such as K1-16.

5 INTERSTELLAR MEDIUM

In the last year, Herbst, F. De Lucia (OSU Dept. of Physics), and colleagues have used millimeter-wave laboratory techniques as well as quantum mechanical methods to study rotationally inelastic collisions of important molecules in the interstellar medium. Collisions between HCO^+ and H_2 were investigated with a novel ion cell at temperatures down to 40 K, while collisions between CO and H_2 were investigated theoretically with a potential energy surface modified to fit experimental data on pressure broadening cross sections.

Herbst's program of research into the gas-phase and grain-surface chemistry of interstellar clouds continues, with an emphasis on star formation regions. With Y. Aikawa (Kobe), Herbst has modeled the gas-phase chemistry of protoplanetary disks surrounding T Tauri stars, and investigated deuterium fractionation and the effect of shielding ultraviolet radiation by ambient clouds. Herbst, Aikawa, and other Japanese colleagues have studied the gas-phase chemistry of the collapsing prestellar core L1544 and used their results to constrain the collapse. With former postdoc D. Ruffle, Herbst has continued to improve models of the gas-phase and grain-surface chemistry occurring in quiescent cores. Ruffle and Herbst have now included photochemistry on grain surfaces in their models, and have elucidated the physical conditions under which CO_2 ice can grow. In a collaboration with D. Williams (UCL) and his student, Herbst and Ruffle have simulated the well-known relationship between visual extinction and water ice determined for sundry sites throughout the Taurus cloud.

Herbst, P. Caselli (Arcetri), and T. Stantcheva (OSU Physics) have simplified and corrected their modified rate equation approach to diffusive surface chemistry on grains, which is the current method used in the large gas/grain chemical models. This approach has been tested for a simple system against a corrected Monte Carlo algorithm. With I. Smith (Birmingham), and D. Talbi (Nice), Herbst has shown that a proposed gas-phase mechanism for the formation of pre-biological molecules in dense interstellar clouds is incorrect.

Sellgren is supervising the Senior Honors thesis of Mark Pitts, an OSU undergraduate majoring in Physics and Astronomy, on the excitation of molecular hydrogen emission in the reflection nebula NGC 7023, based on Infrared Space Observatory spectroscopy. Sellgren plans to supervise the Ph.D. thesis of Pizagno, in a study of dust composition in diffuse and molecular gas, using 2 μm spectra to classify reddened stars selected from 2MASS, then obtaining 3 μm spectra of the stars classified as O, B, and A. Sellgren is completing work on a study of aromatic hydrocarbon emission in NGC 7023, based on ISO spectroscopy, in collaboration with C. Moutou (ESO), A. Léger and L. Verstraete (U. Paris-Sud), M. Werner (JPL), and Pitts. An and Sellgren are writing a paper on an imaging study of molecular hydrogen, 2 μm dust emission, and the 3.3 μm aromatic hydrocarbon emission band in NGC 7023. Pizagno, K. Uchida (Cornell), Sellgren, and Werner are finishing work on theoretical modeling of aromatic hydrocarbon emission. R. Smith (U. New South Wales), Sellgren, and others recently finished a study of the distribution of ice in molecular clouds toward the Coalsack.

Chen and Pradhan presented an analysis of data from planetary nebulae to demonstrate fluorescent excitation of spectral lines as a function of temperature, luminosity, and the distance of the emitting region from the central star of the nebula. They studied a number of line ratios of [Fe VI] in high-excitation planetary nebulae, and found varying effects of fluorescence that should be included in spectral formation and diagnostics of H II regions in general.

6 MILKY WAY STRUCTURE

Gould is serving on the Science Team of the FAME satellite, currently scheduled as a 2004 NASA MIDEX launch. Gould's FAME-related interests include measuring the absolute magnitude of RR Lyrae stars, measuring the local mass density of the Galactic disk, and the study of red and white dwarfs. In preparation for FAME observations, Gould and Salim are working on redesigning the FAME input catalog with the aim of taking advantage of FAME's newly discovered ability to observe faint targets.

Sellgren and Terndrup, in collaboration with S. Ramírez (Caltech), R. Blum (CTIO), and D. Figer (STScI), continue to work on abundances of stars in the central 60 parsecs of the Galaxy. Sellgren, DePoy, Blum, and Ramírez are also studying stellar populations in the central 5 parsecs of the Galaxy, using spectroscopy for spectral classification of a wide field and adaptive optics infrared imaging of a smaller field.

Chanamé, Gould, and Miralda-Escudé are working to develop methods to detect the cluster of stellar-mass black holes that is predicted to surround Sgr A*. Miralda-Escudé is continuing work on this subject to study the rates at which these black holes should be ejected in encounters and captured by Sgr A*, and also to estimate the rate at which captures by the central black hole would produce detectable gravitational waves if similar black hole clusters were present in other galaxies.

7 GALAXIES

Frogel, Stephens, and collaborators analyzed the stellar populations present in M31 with nine sets of adjacent HST NIC1 and NIC2 fields, with galactocentric distances ranging from $2'$ to $20'$. These observations provide some of the highest resolution measurements to date. The tip of the red giant branch is clearly visible at $M_{\rm bol} \sim -3.8$, and the tip of the asymptotic giant branch (AGB) extends to $M_K \sim -8$, significantly fainter than has been previously claimed. There are possibly a few LPVs brighter than the tip of the AGB; however, most of the blue ($J-K < 1.6$) stars observed brighter than this are blends. Significant field-to-field variations were seen in the luminosity functions; however, simulations show that these differences can be produced by blending in the higher surface brightness fields.

Stephens and Frogel used Gemini QuickStart infrared observations of the central $22''$ of M33 to analyze its stellar populations. Based on the slope of the giant branch, they estimate the metallicity of the old component to be -0.54. From the luminosity of the most luminous stars, they hypothesize two bursts of star formation ~ 2 and ~ 0.5 Gyr ago. The stellar luminosity function (LF) has a significantly different slope from that of the Galactic bulge, possibly due to the young stellar component of M33. Combining the infrared Gemini data with optical HST WFPC 2 data reveals a color-magnitude diagram (CMD) populated by young, intermediate, and old stellar populations. Neither the LF nor the CMD shows significant radial variation in the range $3-10''$.

Kassin, Frogel, and Pogge are analyzing ground-based images of the nearby merger, the "Antennae" (NGC 4038/9). These images, in optical and near infrared bands, are examined on a pixel-by-pixel basis to produce maps of stellar populations and extinction. Analysis of the diffuse light (i.e., light not present in star clusters or the nuclei of the galaxies) shows the morphological properties of the Antennae in greater detail than previous analyses. The K band image, in particular, is useful for tracing the old underlying disk populations and locating star formation under heavy dust obscuration.

Alam and Ryden made a study of the apparent axis ratios of galaxies in the Sloan Digital Sky Survey Early Data Release. They find that galaxies with de Vaucouleurs profiles have axis ratios which are strongly inconsistent with their being a population of randomly oriented oblate spheroids. The red ($u - r > 2.22$) de Vaucouleurs galaxies are slightly less flattened, in projection, than blue ($u - r < 2.22$) de Vaucouleurs galaxies. Red galaxies with exponential profiles, by contrast, are very much flatter than blue galaxies with exponential profiles. The red exponential galaxies are primarily disk galaxies seen nearly edge-on, and are reddened by dust, rather than having an intrinsically red stellar population.

Weinberg and collaborators at U. Mass. (N. Katz, M. Fardal, C. Murali), Harvard (L. Hernquist), Arizona (R. Davé) and Pittsburgh (J. Gardner) are using hydrodynamic simulations to study the physics of galaxy formation and to obtain predictions for galaxy properties and clustering. They completed one paper on the assembly history of galaxies in these simulations, showing that they gain most of their mass by smooth accretion rather than by mergers, and another on the sub-millimeter galaxy population, showing that the simulations could account for observed sub-mm counts with plausible assumptions about the dust emission spectrum. Berlind and Weinberg analyzed these simulations to compute the halo occupation distribution (the number of galaxies in halos as a function of halo mass) and compared the simulation results to predictions of the semi-analytic models of A. Benson (Caltech) and collaborators, finding remarkably good agreement between the two methods. Berlind and Weinberg also completed a comprehensive study of the influence of halo occupation parameters on galaxy clustering, concluding that the kind of clustering measurements anticipated from the Sloan Digital Sky Survey should eventually yield an empirical determination of the halo occupation distribution, which can in turn test the predictions of galaxy formation theories. In another step along that path, Weinberg participated in the first paper analyzing the clustering of galaxies in the Sloan redshift survey.

Alam, Bullock, and Weinberg carried out analytic investigations of the central density of dark matter halos, proposing a new measure for comparing theoretical predictions to observations. They confirmed previous findings that the conventional version of the cold dark matter (CDM) model with a cosmological constant predicts central densities higher than those inferred from rotation curves of low surface brightness galaxies. They showed that a model with warm dark matter performs substantially better in this regard, but they also showed that a moderate change to the conventional CDM model – a tilt of the inflationary spectrum to $n \approx 0.9$ – allowed it to match the data as well as the warm dark matter model. Fields, Kravtsov, and Weinberg used N-body simulations to derive the relation between the amplitude of mass fluctuations, the value of the matter density parameter, and the amplitude of the cluster-mass correlation function. These results can be applied to future weak-lensing measurements of the cluster-mass correlation function to obtain constraints on the density parameter and fluctuation amplitude.

Kravtsov and Bullock, as part of a large collaboration between OSU, UCSC, NMSU, and Hebrew University, studied the angular momentum distribution within dark matter halos, developing a model for the acquisition of angular momentum via mergers. This study is important for understanding how disk galaxies formed and how their current observed properties evolved. In addition, in collaboration with P. Colín (UNAM, Mexico), Bullock and Kravtsov repeated their analysis for halos formed in a Warm Dark Matter scenario.

Tinker and Ryden have simulated, using an n-body tree code, major mergers of galaxies. The morphology of the merger remnant is found to be dependent on the presence or absence of supermassive black holes in the progenitor galaxies. If one of the progenitors has a central black hole with mass $\sim 0.2\%$ of the stellar mass, then the effect of the black hole is two make the central regions of the merger remnant more nearly spherical, with a characteristic time scale of a few gigayears. Ongoing work is studying the effects on the structure of the merger remnant of a tightly bound binary black hole, expected to form when both progenitors contain central supermassive black holes.

Kaufman, K. Sheth (Caltech), E. Brinks (U. Guanajuato), B. Elmegreen (IBM), D. Elmegreen (Vassar), C. Struck (Iowa State), and M. Thomasson (Onsala) made a detailed study of the distribution of ^{12}CO $J = 1 \rightarrow 0$, H I, and Hα emission in the interacting pair NGC 5394/95, as part of their continuing work on galaxy pairs involved in grazing encounters. NGC 5394 contains a central starburst similar in radio continuum luminosity and linear size to the M82 starburst. In NGC 5394, 80% of the CO emission detected by BIMA is from the starburst region. An encounter simulation finds that a considerable amount of gas falls into the central region early in the collision. Comparison of NGC 5394 with two other systems (IC 2163/NGC 2207 and NGC 2535/36) suggests that in prograde grazing encounters a central starburst may not develop until near the end of the ocular phase. In collaboration with M. Klarić, they have mapped the interacting pair IC 2163/NGC 2207 in the λ 6 cm radio continuum with $1.5''$ resolution. One goal is to provide clues as to the nature of an unusually energetic region on one of the outer spiral arms.

Monier continued work with D. Turnshek, S. Rao, and D. Nestor (U. Pittsburgh), F. Briggs (Kapteyn), and W. Lane (USNRL) to investigate the properties of galaxies responsible for damped Lyα absorption lines at low redshift. Their sample includes the lowest redshift ($z \approx 0.09$) damped Lyα system known, toward the quasar OI 363, in which the absorber is associated with a low surface brightness galaxy primarily visible in the infrared. The results in general suggest that damped Lyα galaxies are drawn from a wide variety of gas-rich galaxy types.

8 AGN & QUASARS

Monier, Osmer, J. Kennefick (Caltech), and P. Hall (Princeton/Catolica) worked on preparing results of the BTC40 quasar survey for publication; issues resolved included characterizing the photometry of the data. This multicolor (V, I, Z) search for quasars at $z > 5$, covering 36 square degrees, was undertaken to investigate the evolution of quasars and to examine the faint end of the quasar luminosity function at high redshifts. By using color–color diagrams, possible quasars were distinguished from stars and suitable candidates were selected for follow-up spectroscopy. The BTC40 survey has discovered two quasars with $I < 20$ at redshifts of 4.6 and 4.8, consistent with the results of the brighter Sloan Digital Sky Survey.

P. Martini (OCIW), Pogge, An, and S. Ravindranath (OCIW) have completed a Hubble Space Telescope study of Seyfert 2 host galaxies using NICMOS. They find very few nuclear stellar bars in these galaxies (about 20%), suggesting that such dynamical structures are not the most important fueling mechanism in low-luminosity active galactic nuclei (AGN), contrary to some theoretical expectations. Pogge, in collaboration with Martini and J. Shields (Ohio U.), has started a new project with HST to acquire optical spectra with STIS of the nuclei of Seyfert 2's with distinct, apparently unobscured nuclei. The goal is to search for weak broad lines in direct light that would be overwhelmed by starlight in ground-based spectra, as well as to study the properties of the so-called "featureless continuum" in Seyfert 2's. Data collection for the project began in Summer 2001 and will proceed through the beginning of 2003.

Vestergaard is continuing a spectroscopic program to study the narrow C IV λ1549 intrinsic absorbers in a large sample of moderate-redshift quasars. Preliminary results show no immediate differences in the frequency of intrinsic absorbers with radio type; with the exception that the strongest of these intrinsic absorbers occur in radio-loud objects, with preference for highly inclined objects. This supports the idea that the narrow line absorbers are equatorial in origin, similar to the more dramatic broad absorption line troughs seen almost exclusively in radio-quiet quasars.

Vestergaard and P. Barthel (Groningen) continue to study the spectral properties of $z \geq$1.5 quasars for (subtle) clues to the unknown fundamental properties responsible for the powerful radio emission observed in a small fraction of quasars. To first order, the radio-quiet and radio-loud populations have similar spectral properties; the few known exceptions are that the radio-loud quasars are brighter in X-rays, have much stronger radio emission, and lack the broad absorption lines seen in $\sim$10% of radio-quiet quasars. The reasons are still unknown.

Vestergaard, Peterson, and Mathur have started an investigation of the iron emission in a large sample of nearby active galaxies, using data from radio to X-ray energies. Observations are underway, and will include data from both ground-based and space-based telescopes (HST, ROSAT, RXTE, ASCA, Chandra, & XMM). The goal of the project is to identify the properties of active galaxies favorable for strong iron emission and to constrain the vast parameter space which current theoretical models must cover, complicating the theoretical approach in explaining this important line emission.

With M. Dietrich, I. Appenzeller, and S. Wagner, Vestergaard is investigating the iron emission from high-redshift ($z \gtrsim 3.4$) quasars to attempt to constrain the epoch of early star formation in the universe. Combining the relative Fe II to Mg II strength measured in high-redshift quasars with chemical evolutionary models, the current data show that major star formation activity in the host galaxy of these quasars must have already started at an epoch corresponding to $z_f \approx 10$ when the universe was less than 0.5 Gyr old.

Peterson is continuing his multiwavelength monitoring programs on AGN, including a recently completed large multinational program to study optical, UV, and X-ray variations in the narrow-line Seyfert 1 galaxy Akn 564. This program consisted of optical photometry and spectroscopy from MDM and other observatories, UV spectrophotometry with Hubble Space Telescope, and X-ray observations with ASCA and RXTE. The principal results of this program were: (1) the hard and soft X-ray components vary strongly and in phase, (2) the rapid, strong variations seen in X-rays are not obviously correlated with the much weaker continuum variations seen in the UV/optical band, and (3) throughout the UV and optical, the variations at longer wavelengths follow those at shorter wavelengths, with delays amounting to more than ~ 2 days between 1365 Å and 6900 Å.

Romano, Mathur, and J. Turner (NASA/GFSC) have been involved in the analysis of the ASCA data collected during the multiwavelength campaign to monitor Akn 564. Furthermore, Romano and Mathur are involved in the FUV (FUSE) spectroscopy of Akn 564 with Pogge, Peterson, and Kuraszkiewicz (CfA), and are studying the SED of Akn 564. Romano has also been involved in the analysis of the ASCA data obtained during the multiwavelength monitoring campaign on another narrow-line Seyfert 1 galaxy, Ton S180, led by Turner.

Peterson and Pogge, with L. Ferrarese, D. Merritt (Rutgers) and A. Wandel (Hebrew U.), are investigating the relation between host galaxy bulge velocity dispersion and the central black hole mass inferred from reverberation mapping measurements. Their first results indicate that active galaxies show the same strong correlation between these properties seen in quiescent galaxies. This program is continuing.

Onken and Peterson are reanalyzing data from earlier reverberation mapping programs, using improved calibrations and analysis techniques. In their analysis of NGC 3783, they now find a clear virial-like correlation between time lag and emission-line width, as previously found in NGC 5548, 3C 390.3, and NGC 7469.

Peterson is leading the development of a concept for a high-Earth-orbit multiwavelength observatory called

Kronos that will be submitted to NASA as a Medium Explorer proposal. Kronos is designed to map the environments of black holes and other accretion-driven sources, attaining microarcsecond resolution by use of time-based methods such as reverberation mapping, Doppler tomography, and eclipse mapping. As part of this program, Collier, Peterson, and K. Horne (St. Andrews) have continued to carry out numerical simulations to quantify the observational requirements for reverberation-mapping experiments with Kronos. These simulations show that even fairly complex geometries can be successfully mapped with the data expected from Kronos.

As part of an undergraduate honors thesis under the direction of Peterson, K. Gilbert is carrying out an analysis of Balmer-line variability in active galactic nuclei, with the goal of exploring the relation between the continuum and emission-line amplitudes of variation. As the first part of this investigation, she has carried out an extensive series of tests designed to improve AGN cross-correlation methodology.

Alam and Miralda-Escudé have completed a project to calculate the expected absorption of ionizing radiation and Lyα emission from halo gas around quasars, assuming that quasars are located in the same halos that give rise to damped Lyα systems when there is no active quasar. Zheng and Miralda-Escudé have developed a code to do Monte Carlo simulations of the scattering of Lyα photons in a cloud with an arbitrary three-dimensional gas density distribution; this code produces simulated images and spectra of the Lyα emission line generated from either external irradiation or internal ionization and excitation. The code is being applied to oblate models of damped Lyα systems with and without rotation.

Monier and Mathur analyzed associated UV absorption by C IV, N V, and Lyα in HST-FOS spectra of MR2251−178, a radio quiet quasar with an X-ray warm absorber. Photoionization modeling using the properties of the X-ray absorber provided column density predictions for UV absorption that were in good agreement with the equivalent widths actually measured in the HST data. This strongly suggests the UV and X-ray absorption is occurring in the same gas. The UV/X-ray model provides valuable information about the physical conditions and ionization state of the absorbing gas.

Pradhan recently predicted the existence of X-ray photoabsorption features due to the KLL resonances in O VI; such features have been detected by the Chandra X-ray Observatory, in the "dusty warm absorber" in the AGN MCG-6-15-30. The observations helped establish that the spectra are not relativistically broadened due to the proximity of a massive black hole, as thought earlier. This work is also useful in the determination of column densities of two adjacent ionization states, O VI and O VII, from the same wavelength range.

Oelgoetz and Pradhan have performed atomic calculations for X-ray line intensities of the Kα complex of helium-like iron. The calculations have shown that these features may be dominated by the dielectronic satellites of the resonance line. As such, the well-known Kα lines of iron in AGN may be extremely temperature sensitive, and hence may act as diagnostics of ionized accretion disks, accretion flows, flares and Kα temporal-temperature variability in AGN.

Boyd and Osmer, in collaboration with M. Famiano and J. Vandegriff (OSU Physics) and T. Kajino (Tokyo), studied the interactions between jets (such as those emanating from AGN) and clouds (known to exist around AGN), in order to determine the atomic nuclei that would be produced by their interactions. It was found that jets of primordial material, moving with energies of $\sim$ 100 MeV per nucleon, could break up the primordial ^{4}He to form ^{2}H and ^{3}He in amounts well in excess of their usual abundances. This form of production might well explain the anomalously high ^{2}H abundance observed in absorption spectra from distant quasars.

9 LARGE SCALE STRUCTURE

Weinberg, with R. Croft (Harvard) and collaborators from Chicago, Santa Cruz, San Diego, Harvard, and U. Mass., measured the flux power spectrum of Lyα forest absorption in a large sample of quasar spectra, and used it to infer the slope and amplitude of the matter power spectrum at redshift $z \approx 3$. By combining this result with constraints from microwave background fluctuations and galaxy cluster properties, they derived constraints on cosmological parameters.

In collaboration with A. Klypin (NMSU), Y. Hoffman (Hebrew U.), and S. Gottlöber (Potsdam), Kravtsov worked on constrained simulations of the local Universe. Such simulations use the observed peculiar velocity field of galaxies to put constraints on the initial conditions, in order to reproduce the observed large-scale density field in the framework of a given cosmological model. Dissipationless and gas-dynamics simulations were run to demonstrate the power of the method, and to address a number of questions such as (1) the "coldness" of the local velocity field, (2) the validity of the Virgocentric infall model, (3) the observational signatures of the gas in the local supercluster, and (4) the X-ray properties of the Virgo cluster.

During the past year, Kravtsov has dedicated substantial effort to developing and testing a new adaptive mesh refinement code for cosmological gas dynamics simulations. The code is designed to handle an extremely high dynamic range, beyond the capabilities of the eulerian uniform grid or SPH algorithms. Tests show that the developed code performs very well compared to other cosmological gas dynamics codes.

Ryden and L. Strigari (OSU Physics) are examining the effects of bias on the properties of voids. As a test case, they have been examining the n-body cosmological simulations of Kauffmann et al., in which the locations and properties of galaxies within collapsed halos are determined by simple prescriptions adopted from semi-analytic models of galaxy formation. By applying void-finding algorithms to the simulations, Ryden and Strigari find that the voids defined by the galaxies are significantly larger than the voids defined by the underlying mass distribution. The effects of galaxy biasing on void size are larger than the effects of peculiar velocity distortion or the effects of changing the cosmological constant.

10 MICROLENSING

Gould is currently investigating various applications of microlensing, including the detection of extrasolar planets, microlensing observations toward M31, developing new methods to extract additional information about individual microlensing events, investigation of the relation between star counts and microlensing, and measurement of the masses of nearby stars using astrometric microlensing. Gould is Principal Investigator on a SIM Microlensing Key Project whose primary aim is to measure the mass function of both dark and luminous objects in the Galactic Bulge.

An, DePoy, Gould, and Pogge are working in the PLANET collaboration to search for extrasolar planets by intensive follow-up observations of ongoing microlensing events. PLANET has substantial observing time on four telescopes: the Yale-CTIO 1m, the SAAO 1m, the Canopus 1m in Hobart, Tasmania, and the Perth 1m in Western Australia.

11 COSMOLOGY

Scherrer, McDonald, and Walker worked on an investigation of the effect of residual relic particle annihilations on the spectrum of the Cosmic Microwave Background (CMB). They found that interesting limits can be placed on such annihilations; these limits are competitive with the best previous limits from primordial nucleosynthesis. Scherrer also collaborated with S. Hannestad (Denmark) on a study of the effects of non-standard ionization histories on the observed CMB fluctuations.

Recent CMB observations can be combined with limits from Big Bang Nucleosynthesis (BBN) to constrain new neutrino physics (such as a neutrino chemical potential), but these constraints are very sensitive to the estimates of other cosmological parameters. Scherrer, Steigman, Walker, and J. Kneller (OSU Physics) examined the sensitivity of such constraints to the prior assumptions about the parameters. Kneller and Steigman are extending this work, using BBN and CMB data to constrain non-standard models of cosmology, containing quintessence or non-minimally coupled scalar fields.

In collaboration with X. Chen (now at UCSB), Steigman and Scherrer examined the effect on primordial nucleosynthesis of quintessence models in which the quintessence field couples to the scalar curvature. Such models lead to a changing gravitational constant and are thus sharply constrained by observations. This work showed that it is possible to construct quintessence models of this type which satisfy all the observational constraints and still lead to an interesting reduction in the primordial helium abundance.

Ryden is writing an undergraduate cosmology textbook, tentatively titled *Introduction to Cosmology*, to be published by Addison Wesley Longman in Fall 2002.

12 ATOMIC ASTROPHYSICS

The group of Pradhan, Nahar, Chen, Delahaye, and Oelgoetz is involved in research for various astrophysical and atomic radiative and collisional processes. They also collaborate with H. Zhang (LANL), E. Werner (U. Stuttgart), C. Zeippen (Observatoire de Paris), C. Mendoza and M. Bautista (IVIC, Venezuela), A. Sigut (U. Western Ontario), and F. Keenan (Queens U., Belfast).

The group headed by Pradhan is part of the international Iron Project (IP), which studies and calculates accurate atomic parameters for collisional excitations, photoionization, and fine structure bound-bound transitions, primarily for iron and iron-peak elements. Using the relativistic Breit-Pauli R-matrix method in the close coupling approximation developed under the IP, highly accurate large-scale calculations are being carried out for both atomic radiative and collisional processes. Work on electron impact excitation collision strengths for the complex and astrophysically important ion, Fe XVII, has been completed by Chen and Pradhan after three years of effort. The electron impact excitation collision cross section for O VII, an important ion in X-ray plasma diagnostics, has been obtained by Delahaye and Pradhan.

Photoionization cross sections of highly charged ions are now being calculated more accurately, including relativistic effects and the radiation damping of low-lying resonances in the Breit-Pauli R-matrix method. Detailed photoionization cross sections for He-like and Li-like ions have been obtained for O VI, O VII, C IV, C V, Fe XXIV, and Fe XXV. These ions are observed frequently in Chandra X-ray spectra.

Nahar is theoretically delineating, using the relativistic Breit-Pauli approximation, the features of photoionization cross sections that have been observed recently in the sophisticated experiments at Aarhus University, the Advanced Light Source in Berkeley, and France, for ions such as C II, O II, and O IV.

A unified method for total electron-ion recombination rates, which accounts for both the radiative and dielectronic recombinations in a self-consistent manner, was developed by Nahar and Pradhan and was later extended to include relativistic effects by Zhang et al. Total and level-specific rate coefficients are now available for the highly charged ions C IV, C V, Fe XXIV, Fe XXV, O VI, and O VII. Pradhan and collaborators have recently obtained recombination cross sections and rates for Fe XVII and C III that agree within 10-15% with the highly resolved measurement. Work is complete for state-specific and total recombination rate coefficients for Ni II after two years of effort. Nahar is analyzing the recombination rates for the carbon-like ions Ar XIII, Ca XV, and Fe XXI.

Study of radiative transitions of bound-bound levels is another research interest of Pradhan's group. The relativistic BPRM method allows calculations of oscillator strengths for a large number of electric dipole allowed, intercombination transitions with consistent accuracy, as needed for radiative-collisional models. Work is ongoing to obtain large sets of fine structure levels and oscillator strengths for a number of ions, such as Fe XVII, S II, O IV, C II, C III, and lithium-like ions such as C IV, N V, and O VI.

Recently Pradhan and his group have been engaged in predicting absorption lines in the X-ray region that can be used for identification of spectral lines detected by space-based observatories such as Chandra and XMM. Pradhan showed a new way of analyzing these lines by calculating the "resonance oscillator strength" $\bar{f}_r$ in terms of the differential oscillator strengths $df/d\epsilon$ of autoionizing resonances in photoionization cross sections. This requires high resolution of the fine structure autoionizing resonances in the bound-continuum cross sections. Nahar and collaborators have predicted such lines for C IV and Fe XXIV. Work is in progress for X-ray line detection for the oxygen isonuclear sequence of ions.

13 NUCLEAR ASTROPHYSICS

In the high-temperature environment thought to characterize the r-process, nuclei might be expected to spend some fraction of their time in excited states. This would modify the beta-decay rates of the nuclei along the r-process path, and hence the predicted abundances of the r-process nuclides. Boyd, M. Famiano (OSU Physics), T. Kajino, M. Terasawa, and K. Otsuki have included, in an r-process code, the possibility that excited states could decay. The excited states were generally found to decay considerably faster than the ground states, due to nuclear structure effects; the resulting enhancement of the decay rates allowed the r-process to proceed more rapidly than it otherwise might, making it easier for seed nuclei to reach the mass 195 u peak, probably the most significant challenge to r-process models. The mass 195 u peak was enhanced by a factor of ~ 3 in many of the models run.

With R. Gruenwald and S. Viegas (São Paulo), Steigman continued to investigate sources of potential systematic errors in using emission-line observations of extragalactic H II regions to zero in on the primordial abundance of ^{4}He. Most recently, they revisited the question of ionization corrections for unseen neutral helium (or hydrogen) for H II regions ionized by clusters of young, hot, metal-poor stars. They explored the time evolution of the ICF as the stellar cluster ages and the photoionization spectrum evolves. Using a combination of observational parameters which constrain the overall photoionization rate and the hardness of the spectrum, Gruenwald, Steigman, and Viegas find that the Izotov-Thuan estimate of the primordial helium abundance should be reduced from $Y = 0.244 \pm 0.002$ to 0.238 ± 0.003.

14 NEUTRINO ASTROPHYSICS

Boyd, J. Beacom (Caltech), and A. Mezzacappa (Oak Ridge) studied the spectrum of neutrinos that would be produced from a supernova if the central collapse went to a black hole while the neutrino luminosity was relatively large. It was shown that the neutrino termination would produce a timing signal of the instant of collapse to about 1 ms, as determined from SuperKamiokande. A supernova neutrino detector sensitive to neutral currents would then be able to determine neutrino masses for ν_μ, $\bar{\nu}_\mu$, ν_τ, and $\bar{\nu}_\tau$ to as low as a few ev/c^2, for a supernova at the Galactic center.

As part of the development effort on OMNIS, the Observatory of Multiflavor NeutrInos from Supernovae, Boyd, J. Zach, A. Murphy, and D. Marriott (OSU Physics) have done a Monte Carlo simulation of a variety of possible detector configurations that might be built. OMNIS will observe supernova neutrinos by observing the neutrons produced by the interaction of the neutrinos with nuclei, specifically lead. The Monte Carlo simulation determined the optimum parameters of the components of OMNIS in a way that included both neutron detection optimization and cost optimization.

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