The Ohio State University
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This annual report covers the period 2001 September through 2002 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. Weinberg spent his sabbatical leave at the Institute for Advanced Study (Princeton) and the Institut d'Astrophysique de Paris. Frogel was on leave at Lawrence Berkeley National Laboratory and NASA Headquarters in Washington, DC.

Michele Kaufman and Smita Mathur held appointments as Research Scientists, David Ennis and Eric Monier were Lecturers, and Sultana Nahar was a Senior Research Associate. Emeritus members of the Astronomy Department are Eugene Capriotti, George Collins II, Stanley Czyzak, Geoffrey Keller, William Protheroe, and (since July 2002) Robert Wing.

The staff of the Imaging Sciences Laboratory (ISL) included Bruce Atwood, Ralph Belville, David Brewer, Paul Byard, Mark Derwent, Jerry Mason, Thomas O'Brien, Daniel Pappalardo, David Steinbrecher, and Edward Teiga. 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 to work full-time 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, David Graff, Eric Monier, and Marianne Vestergaard (Columbus Fellow).

Graduate students in the Astronomy Department during the academic year included Khairul Alam, Jin An, Nikolay Andronov, Christopher Burke, Julio Chanamé, Guo-Xin Chen, Franck Delahaye, Dale Fields, Susan Kassin, Juna Kollmeier, Jennifer Marshall, Grant Newsham, Christopher Onken, Josh Pepper, James Pizagno, Patrizia Romano, Samir Salim, Adam Steed, Jeremy Tinker, Rik Williams, and Zheng Zheng. Justin Oelgoetz is an OSU Chemical Physics graduate student working on his Ph.D. thesis with Pradhan.

Graduate students arriving in the summer of 2002 were Deok-Keun An, Misty Bentz, Stephan Frank, Angela Hanson, Christopher Morgan, and Jai-Yul Yoo. Students completing their Ph.D. were Jin An (now at Cambridge, UK), Romano (now at Osservatorio Astronomico di Brera, Italy), and Salim (now at UCLA). The Masters Degree was awarded to Alam, Delahaye, and Kassin.

Peterson continued as a member of the NASA Structure and Evolution of the Universe Subcommittee. He has also been appointed to the National Astronomy and Astrophysics Advisory Committee (NAAAC), which was established to facilitate greater cooperation between the National Science Foundation and NASA.

Sellgren continues to serve on the NASA Space Science Advisory Committee; the AURA Observatories Visiting Committee; the Scientific Organizing Committee for Galactic Center 2002, a conference to be held in November 2003; and the Scientific Organizing Committee for Astrophysics of Dust, a conference to be held in May 2003. Sellgren has also been invited to serve on the SOFIA Science Council.

2. TELESCOPES AND INSTRUMENTATION

OSU has a one-quarter share of the observing time on the 2.4-m and 1.3-m 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 8.4-m mirrors, will be the world's largest telescope on a single mount and will have a 22.8 m baseline for interferometric observations. During the last year, polishing continued on the first primary mirror; the figure of this primary is below 130 nm rms. The exterior and interior finishing work on the enclosure on Mt. Graham is complete and the entire building is habitable. The telescope structural components were completed about a year ago in Italy; tests of the structure were made and found to be within specification. The structure was dissembled and successfully shipped to Mt. Graham. All of the major pieces of the telescope are now in Arizona; some are already on Mt. Graham and are in the process of being re-assembled inside the building. First light for the LBT is expected in mid–2004.

Work continues here in Ohio on the primary aluminizing system for the telescope. The aluminizing bell jar and dummy mirror cell arrived in Columbus safely. Our instrumentation staff are in the process of installing the equipment needed for the aluminizing system.

The project to construct a multi-object double spectrograph (MODS) for the LBT is progressing. A large effort has gone into design of the various components of the spectrograph and there are many sub-systems that are complete or in fabrication. An initial incarnation of MODS is expected to be deployed about the time of LBT first light in mid–2004. Details on MODS progress are available at `www.astronomy.ohio-state.edu/LBT/MODS`.

The ISL staff 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, and TIFKAM and CCDS at MDM Observatory.

3. SOLAR SYSTEM AND PLANETS

DePoy, Fields, Gould, and Pogge are working in the μFUN collaboration to search for extra-solar planets by intensive follow-up observations of ongoing microlensing events. μFUN has substantial observing time on three telescopes, the Yale-CTIO 1-m, the Mount Stromlo 74″, and the Wise 1-m.

Pepper and Gould analyzed the statistical properties of all-sky surveys for finding transits of extrasolar planets. They proposed a telescope design and an observing program for an optimal survey of this type.

DePoy, Gould, Morgan, and Pepper are developing a 1″ telescope system for an all-sky search for planetary transits.

4. STARS AND BINARIES

Terndrup is continuing an extensive survey to find and characterize hot horizontal-branch stars in the nuclear bulge, in collaboration with R.C. Peterson (Astrophysical Advances), E.M. Green (Arizona), A.R. Walker (NOAO/CTIO), and E. Sadler (Sydney). In 2001, they completed a deep imaging survey in *UBV* and the SDSS *u*-band using the MOSAIC camera on the Blanco 4-m telescope at CTIO, achieving imaging down to $B \approx 22.5$. Data reduction is underway. Preliminary color-magnitude diagrams show that the SDSS *u* filter in combination with Johnson *U* provides an efficient way to detect extreme horizontal–branch stars, those with temperatures in excess of 16,000 K, which are thought to produce the ultraviolet excess in ellipticals and the bulges of other spirals.

With N.B. Suntzeff (NOAO/CTIO) and V.V. Smith (UTEP), Terndrup completed a spectroscopic survey at 2.3 μm to measure the abundance ratio $^{12}CO/^{13}CO$ (via the first–overtone CO bands) as probes of the core-surface mixing in evolved bulge and globular cluster stars. In ω Centauri, they find that all the bright giants in their sample show evidence for efficient mixing (i.e, $^{12}CO/^{13}CO \approx 4$, in contrast to the solar value of 90), over the full range of [Fe/H] in that cluster. The metal-poor stars in the bulge, which may be analogous to local thick disk objects, are similarly mixed; all stars with $[Fe/H] > -0.7$ have $^{12}CO/^{13}CO \approx 10$, indicating less efficient mixing and/or a relatively high turnoff mass.

In collaboration with T.C. Beers (Michigan State) and C. Sneden (Texas), Terndrup, Pinsonneault, Gould, and DePoy have begun a new observational and theoretical effort to obtain fundamental data on nearby subdwarfs whose parallaxes will be measured by SIM or other astrometric satellites. The goal here is to improve estimates of globular cluster distances to a precision of about 5% and thereby reduce the (currently large) errors in their ages by a factor of two, and provide detailed abundances for studies of the early evolution of the galactic halo.

Pinsonneault, Terndrup, and J.R. Stauffer (IPAC) are working on a related project to define accurate photometric diagnostics of distance, age, reddening, and metallicity in open clusters. In particular, they are examining the main sequence/pre-main sequence boundary as an age diagnostic complementary with upper MS ages and lithium ages from very low mass stars.

C. Watson (OSU Physics) and Pinsonneault have included the effects of disk accretion and deuterium burning in models of protostars; they are examining the sensitivity of the stellar birthline to the mass accretion history and the assumed thermal energy content of the accreted matter.

Terndrup and Pinsonneault have also obtained a large sample of high-resolution spectra in the intermediate age clusters NGC 752 and NGC 2420, which are two prototype clusters for the calibration of convective overshoot in stellar evolutionary models. They have also obtained new observations in NGC 5822 (also in collaboration with S. Hawley, Michigan State). The analysis of the intermediate-age clusters is now mostly complete, and includes the efforts of OSU undergraduate Van Nguyen. These data provide the first look at the effects of metallicity on the angular momentum evolution and chromospheric/coronal activity (particularly X-rays) and will yield important calibrating data for the production of giant branch models which properly treat rotationally–induced mixing and dredge-up. Preliminary analysis indicates that the spindown on the subgiant branch cannot be explained if solid-body rotation is enforced through an efficient transfer of angular momentum in the stars' radiative zones, but instead suggests that radial differential rotation occurs. This latter result is what is needed for core-surface mixing in evolved giants.

Chanamé, Pinsonneault, and Terndrup are studying rotationally induced mixing in low-mass (0.8 – $1.5\,M_\odot$) giant stars as a solution to the long-standing discrepancy between the predictions of standard stellar models (which do not include the effects of rotation) and the measured abundances of the CNO isotopes in globular and open cluster giants. The dredge-up of enriched material due to rotationally induced instabilities is enough to explain the observed abundance anomalies given sensible assumptions about the internal transport of angular momentum inferred from helioseismology and the rotation of evolved stars. Ongoing work includes the analysis of the trends of mixing with mass and metallicity; the impact of angular momentum loss by stellar winds and mass loss episodes along the giant branch; and the development of a self–consistent version of the evolution code that would not make assumptions about the transport of angular momentum, but rather would compute it from first principles.

Chanamé and Onken are investigating the photometric properties of known post-asymptotic giant branch stars (post–AGBs) in the Milky Way. In addition to providing the first systematic campaign on this short–lived phase of stellar evolution, the upcoming CTIO observations will establish the best method for selecting post–AGBs from field stars of similar color.

Andronov and Pinsonneault continue their research on interacting binary stars. The main focus has been on applying empirical constraints on the angular momentum loss from single stars in open clusters to models of the evolution of cataclysmic variables and blue stragglers produced by mergers of main sequence stars.

Wing has been working with U.G. Jǿrgensen (Niels Bohr Institute) and N. van der Bliek (CTIO) to calculate synthetic colors for cool stars on various photometric systems. Spectra have been computed from model atmospheres produced by the MARCS code, modified to include the opacity from 50 million lines of H_2O, which has important effects on the atmospheric structure and infrared spectra of dwarfs cooler than 3600 K and giants cooler than 3000 K. Synthetic JHK colors reproduce the well-known bifurcation of giants and dwarfs in the two-color diagram. As an additional test of the models, Wing, Jǿrgensen, and van der Bliek are studying the near-infrared spectra of Proxima Centauri, Wolf 359, and several other nearby M dwarfs. The spectra, which extend from 1.2 to 2.5 μm at resolution $R = 1200$, were obtained with OSIRIS at the Blanco 4-m telescope.

Wing and K. Walker, an OSU undergraduate student, are deriving the transformations between a set of 6 large-format narrow-band filters now in use at the MDM Observatory, and Wing's 8-color narrow-band system. The results will make it possible to place new CCD photometry onto the system previously defined by photoelectric work.

S. V. Ramírez (SIRTF Science Center), Sellgren, and R. Blum (CTIO) continue their work on elemental abundances in cool, luminous stars in the Galactic Center. They found in a previous paper that M supergiants and AGB stars in the GC have a distribution of [Fe/H] indistinguishable from that of similar cool, luminous stars in the solar neighborhood. The range of ages for the Galactic Center supergiants and AGB stars, from $\sim$ 10 Myr to $\sim$ 1 Gyr, suggests that some mechanism, or interplay between several mechanisms, in the Galactic Center is holding the iron abundance at a fixed value over a Gyr of star formation. They are currently acquiring data to detemine the ratio of $\alpha-$element abundances to iron abundances, as a clue to the type of stars (high-mass or low-mass) that dominate chemical enrichment in the Galactic Center.

In collaboration with M.J. Seaton (UCL) and C. Mendoza (IVIC, Venezuela), Pradhan has established a database for on-line computation of stellar opacities at the Ohio Supercomputer Center. These 'customized' opacities may be obtained for an arbitrary mixture of elements specified by the user for modeling stellar structure and evolution. Radiative accelerations may also be computed to investigate the effect of radiative 'levitation' versus gravitational settling of elements in stars.

5. INTERSTELLAR MEDIUM

Sellgren is working with Honors undergraduate student M. Pitts to derive the rotational temperature of H_2 in the photodissociation region in the reflection nebula NGC 7023, using spectra of H_2 pure rotational lines obtained with the Short Wavelength Spectrograph on the Infrared Space Observatory. Previous observations of other photodissociation regions show that the rotational temperatures are too high to be explained by current models.

Sellgren and J. An have examined the difference in spatial morphology of the 3.3 μm aromatic emission feature and the 2.18 μm narrow-band continnum filter in the visual reflection nebula NGC 7023. Surprisingly, they find the 3.3 μm emission feature is strongest in narrow filaments, previously detected in fluorescent H_2, but that the 2.18 μm continuum is strongest in a broad region halfway between the illuminating star of NGC 7023 and the filaments observed in the 3.3 μm aromatic feature. Furthermore, the ratio of 2.18 μm flux to 3.3 μm flux decreases with projected distance r from the star as r^{-2}. This suggests that the carriers of the 3.3 μm aromatic emission feature and the 2.18 μm continuum are not identical, as previously assumed. Instead they are separate ISM components, but their flux ratio is regulated by the strength of the stellar illumination.

H. Dinerstein, M.J. Richter, J.H. Lacy (U. Texas) and Sellgren have studied the abundances of S and Ne in two halo planetary nebulae. Both plantaries have similarly low oxygen abundances. However, one planetary has much higher S and Ne than the other. This suggests that using O as a tracer of metallicity for metal-poor populations is uncertain, since it appears that in some cases the evolved star has self−enriched its O abundance by dredge-up, while S and Ne are unlikely to be self−enriched.

Pizagno, Sellgren, K.I. Uchida (Cornell) and M.W. Werner (JPL) are comparing the fraction of total dust emission emitted in the IRAS 12 μm band to predictions from models of various polycyclic hydrocarbon (PAH) models, and to theoretical models for a size distribustion of PAHs. They find that no single analog material fits how the ratio of 12 μm emission to dust emission depends on the temperature of the illuminating star, but that models including a size range of PAH molecules provide a good fit.

In collaboration with D. Talbi (Nice, France), Herbst has shown that the suggestion that gas−phase CO_2 has a low abundance in high-mass star−formation regions because of reactions with molecular and atomic hydrogen is probably incorrect. Both reactions, especially that with H_2, do not occur at large rates because of large activation energy barriers. Also, in collaboration with Talbi, Herbst has shown that a prior suggestion to explain the high deuterium fractionation of the molecule c−C_3H_2 is in error.

Herbst's program of research into the modeling of the gas−phase and grain−surface chemistry of interstellar clouds continues, with an emphasis on star formation regions. Y. Aikawa (Kobe), E.F. van Dishoeck and G.J. van Zadelhoff (Leiden), and Herbst have modelled the gas−phase chemistry of protoplanetary disks surrounding T Tauri stars using the latest radiative transfer techniques and a new physical model for such disks. In addition to comparing theoretical molecular abundances, they simulate actual spectral lines to compare with the observations of radio astronomers. The model allows for inhomogeneities in two dimensions. With former postdoctoral associate D.P. Ruffle and researchers from University College London, Herbst has used his gas-grain chemical code to study the water ice distribution in Taurus and its relation with visual extinction. With S. Saito (Fukui) and other Japanese researchers, Herbst has looked into the correlation between deuterium fractionation and chemical lifetime in dark cloud cores. P.M. Woods (ESO), researchers at UMIST (Manchester, UK), and Herbst have looked into the formation of complex molecules in protoplanetary nebulae. With postdoctoral associate H. Roberts, Herbst has investigated the effect of new rate coefficients on deuterium fractionation and how gas–grain chemical models can be used to reproduce the SWAS results of low gas–phase water and oxygen in an assortment of interstellar objects.

Herbst, P. Caselli (Arcetri), V.I. Shematovich (Moscow), and graduate student T. Stantcheva have continued to study exact methods for understanding how surface chemistry occurs on interstellar grains. Current models contain an approximate technique only. In a recent paper, Stantcheva, Shematovich, and Herbst showed how the direct master equation method can be utilized to solve the problem of chemistry by surface diffusion in an exact manner. Current research on the stochastic, or Monte Carlo, alternative approach is being pursued by graduate student A.J. Kuhlman.

6. MILKY WAY STRUCTURE AND MICROLENSING

Gould is currently focusing his work on applications of microlensing and galactic structure. Microlensing work includes detection of 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 PI 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. Galactic structure work is primarily focused on completing a Revised NLTT Catalog with better astrometry and new optical/infrared photometry, and using the reduced proper motions from this catalog to isolate various Galactic populations for further study.

Pepper, Pogge, and Depoy have been analyzing H and K images of the Galactic Center, using data from the *PLANET* collaboration. They are employing Difference Image Analysis to generate light curves for variable objects near Sgr A* in order to learn more about their nature.

Chanamé, Gould, and Miralda-Escudé investigated the gravitational lensing of background bulge stars by Sgr A*, the supermassive black hole residing at the Galactic Center. They determined that, at any given time, about 2 pairs of resolved, lensed images of background bulge sources are expected to be found if the threshold of detectability is pushed down to $K_{thr} = 21$, and 8 pairs if $K_{thr} = 23$. The monitoring of these lensed images then provides a unique way to detect stellar-mass black holes predicted to cluster around Sgr A*, since if a black hole passes close to a lensed image, it will give rise to a short (weeks long) microlensing event. For a cluster of 20,000 black holes within a radius of 0.7 pc from the Galactic Center, they found a (detectable) microlensing rate of 0.06 yr^{-1} for $K_{thr} = 23$ and moderate magnifications by Sgr A*. For images highly magnified by Sgr A*, the rate of events becomes much higher.

As another method for the detection of a cluster of stellar-mass black holes around Sgr A*, Chanamé and Gould studied the feasibility of using millisecond pulsars as tracers of the mass segregation induced by the presence of such a system. Using a maximum likelihood analysis they determined that, if about 50 objects belonging to any old population ($\gtrsim$ 1 Gyr) and less massive than the black holes are found within a few parsecs of the Galactic Center, any mass segregation (and hence the cluster of black holes) would be reliably identified using only their angular positions on the sky relative to Sgr A*. Given the large uncertainties still involved in the determination of the ages for the most common type of objects in the Galactic Center neighborhood, they proposed millisecond pulsars as the best candidates to do this work, since their ages can be determined by relatively easy measurements of their spindown properties. Furthermore, if both the first and second time derivatives of the period of the pulsars are measured, it is possible to obtain the complete six-dimensional phase-space information on these objects, improving the detection/rejection of mass segregation by about 30%. These conclusions add more scientific justification for the construction of new facilities such as the Square Kilometer Array (SKA), a collection of large radio antennas aimed to improve current detection limits by a factor of 100 or more.

Chanamé, Gould, and Miralda-Escudé are studying the dynamics and long-term stability of the cluster of stellar-mass black holes that is predicted to surround the supermassive black hole at the Galactic Center, Sgr A*. They are developing a Monte Carlo code which accounts for the competing mechanisms that determine the evolution and fate of such a system, among which are ejection of black holes from the cluster, and captures by the central black hole. In addition to the understanding of the stellar and mass distributions in the innermost regions of the Galaxy, another goal of this study is to estimate the rate at which captures of stellar-mass compact objects by the central black hole (either in the Galaxy or in other galaxies) would produce detectable gravitational waves, a key question in light of future experiments such as the Laser Interferometer Space Antenna (LISA).

R. Blum (CTIO), S. V. Ramírez (SIRTF Science Center), Sellgren, and K. Olsen (CTIO)) are studying the star formation history of the central 5 pc of the Galaxy. They have obtained low-resolution $H-$band and $K-$band spectra for roughly 60 stars to derive $T_{\rm eff}$ and $M_{\rm bol}$ for the Galactic Center stars. They place the Galactic Center stars on the H-R diagram, compare their positions to theoretical isochrones with ages between 10 Myr and 12 Gyr, and derive a star formation history for the central 5 pc of the Galaxy.

Ramírez, Sellgren, and Blum are following up on Sellgren's earlier work with J. Carr (NRL) and S. Balachandran (U. Maryland), which found that the abundances of C, N, and O in one Galactic Center M supergiant implied extreme stellar mixing beyond the predictions of the most recent high–mass stellar models. They are currently analyzing CNO abundances in several additional Galactic Center stars, and are proposing to obtain more observations to see if the extremely strong mixing in one Galactic Center M supergiant is unique to that star. If the strong mixing in this one Galactic Center supergiant is not an anomaly, then they will investigate two possible explanations. The first is whether the strong mixing in Galactic Center stars is a result of proximity to the 2.6×10^6 solar mass black hole in the very center of the Milky Way. The second possibility is that the unique star formation conditions (higher gas temperatures, higher gas density, and higher tidal shear) all favor an initial mass function biased towards high–mass stars) in the central 200 pc of the Galaxy. They hope to make this distinction by measuring CNO abundances in Galactic Center stars at a range of projected distances from the massive black hole of 0.2 to 30 pc.

7. GALAXIES

The OSU Bright Spiral Galaxy Survey project, led by Frogel, is nearing completion. Begun in 1995, it has acquired deep $BVRJHK$ images of $\sim$200 bright spiral galaxies, most with accurate photometric calibration. The first Early Data Release was posted to the web (www.astronomy.ohio-state.edu/ survey/EDR) releasing all of the B and H–band images. The full $BVRJHK$ imaging set, with photometric calibrations, is being prepared for release in early 2003.

Monier continued work with D. Turnshek, S. Rao, and D. Nestor (U. Pittsburgh) on the properties of galaxies responsible for damped Lyα (DLA) quasar absorption lines at redshifts $z<1$. DLA absorption is produced by a large column of neutral hydrogen gas residing in a galaxy along the line of sight toward a background quasar. The candidate DLA systems in this sample have been identified through strong Mg II and Fe II absorption seen in ground-based quasar spectra, most recently selected from the early data release of the Sloan Digital Sky Survey. Follow–up UV spectra with HST are then used to look for the expected DLA absorption line. An ongoing companion program of multi-color imaging ($UBRIJK$) of the corresponding quasar fields at the MDM, WIYN, and IRTF observatories is being used to identify photometrically the absorbing galaxies and to determine their morphologies, colors, and star–formation histories.

Monier is using HST–STIS spectra of the gravitationally lensed Cloverleaf quasar H1413+1143 to investigate the transverse sizes of the regions giving rise to DLA absorption at $z\approx1.5$. The H I column densities in three strong intervening absorption systems toward this quasar vary by factors of two or more among the four sight-lines. The absorbers are therefore inhomogeneous over the size scales of $\sim 5\, h^{-1}$ kpc represented by the separations of the lines of sight.

In collaboration with Pogge, Ryden, and T. Statler (Ohio U.), Terndrup is continuing their earlier work on dwarf elliptical galaxies in the Virgo Cluster. The new observations, conducted at the MDM Observatory, extend multicolor imaging of these systems to extremely faint levels and have revealed many instances of complicated substructure (e.g., multiple nuclei or irregular outer isophotes). Color gradients within the galaxies do not correlate either with the average color or with galaxy morphology. This group has also begun to obtain very detailed studies of a few understudied large elliptical galaxies. Among other results, they have uncovered complicated shell structure in NGC 2634, which is part of a small but compact group. At the January 2002 AAS meeting, they presented radial profiles of the surface brightness, isophotal ellipticity, the major axis position angle for the galaxy, and the measured relative colors in the shells. This study incorporates VLA 6-cm observations of this galaxy group with J. van Gorkom (Columbia).

Tinker and Ryden have done a study of the influence of triaxial halos on collisionless galactic disks. Using numerical N-body simulations, they have found that triaxial halos trigger strong bars within disks, even for galaxies with relatively massive bulges. By varying the bulge-to-disk ratio of their models, they created an artificial Hubble sequence, with big-bulged galaxies having higher pitch angles. Ryden is developing an analytic study to explain these results in the context of kinematic density wave theory.

Ryden is studying the dynamics of nucleated dwarf elliptical galaxies. In particular, by examining the interaction between the dense nucleus and the relatively low density core of a dwarf elliptical, she is uncovering indirect evidence about the velocity dispersion and mass density in the central regions of dwarf ellipticals.

8. QUASARS AND AGNS

Monier and Osmer completed their work on the BTC40 survey for quasars at $4.8<z<6$. The survey covers 36 sq. deg. to 3–σ limiting magnitudes of $V=24.6$, $I=22.9$, and $z=22.9$. Follow-up spectroscopy yielded two quasars at $z=4.6$ and $z=4.8$ plus four emission-line galaxies with $z\sim0.6$. Fainter candidates have been selected to $I=22$ for future spectrosopy on 8-m or larger telescopes.

Under the leadership of Peterson, the International AGN Watch has completed a 13–year program of optical spectrophotometric and photometric monitoring of the Seyfert 1 galaxy NGC 5548. The data base accumulated over this period has yielded 1530 continuum measurements and 1248 Hβ emission–line measurements. During the course of a single year, the continuum typically varies by about 10–30 %, but over the entire span of the data, the full range of continuum measurements spans an order of magnitude. The emission–line variations follow those of the continuum with a time delay that is attributable to light travel–time effects within the line–emitting region. This time delay is found to vary from year to year (the observed range is 6 to 26 days) and depends on the mean continuum luminosity; when the central source is in a brighter state, the emission–line lag is longer. This points clearly to an extended line–emitting region in which the observed line response is dominated by the clouds with locally ‘‘optimal’’ conditions for producing the particular line in question.

Peterson, Pogge, Vestergaard, and Onken, with L. Ferrarese and D. Merritt (Rutgers) and A. Wandel (Hebrew Univ.), are investigating the relationship between host-galaxy bulge velocity dispersion and the central black-hole mass inferred from reverberation mapping measurements. They are finding that active galaxies show the same strong correlation between these properties that is found in quiescent galaxies and that the black-hole mass measurements based on reverberation results are accurate to a factor of $\sim$3.

Onken and Peterson, with M. Dietrich (Florida), A. Robinson (U. Hertfordshire), and I. Salamanca (U. Amsterdam), have reanalyzed reverberation mapping data from the Lovers of Active Galaxies collaboration in order to make estimates of the central black hole masses in three Seyfert galaxies. The new masses, for NGC 3227, NGC 3516, and NGC 4593, have now been determined in a manner consistent with previous large compilations, and can be used to further study the relation recently identified between black hole mass and bulge velocity dispersion in both active and quiescent galaxies.

Peterson is leading the development of a concept for a high-Earth-orbit multiwavelength observatory called *Kronos*. It is designed to map the environments of black holes and other accretion–driven sources through tomographic techniques such as reverberation mapping. As part of this program, K. Horne (St. Andrews), Peterson, and H. Netzer (Tel-Aviv) have carried out realistic detailed 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 expeced from *Kronos*.

K. Gilbert (Santa Cruz) and Peterson have completed a study of Hβ variations in NGC 5548 for the purpose of exploring the relationship between the continuum and emission-line amplitudes of variation, i.e., a search for an ‘‘intrinsic Baldwin Effect’’ in the Balmer lines. Such an effect is found and appears to be in good agreement with photoionization-equilibrium model predictions. While the line responds to continuum variations with a decreased amplitude, the AGN continuum ‘‘hardens’’ as it brightens, in such a way that the equivalent width of Hβ changes little in response to reverberation signals.

Pogge and P. Martini (OCIW) have used new and archival WFPC2 imaging to show that all Seyferts in the CfA survey have circumnuclear dust, often in grand design spirals, extending in to the smallest scales visible using *HST*. In particular, the grand design spirals are strongly correlated with large–scale bars in the host galaxies, suggestive of a possible transport of interstellar gas from the host into the nucleus by gravitational torques from the stellar bar. This work required development of a novel image processing technique called ‘‘structure mapping’’ to enhance the images and reveal the near-nuclear absorption features. A companion study comparing a carefully matched host–galaxy sample of Seyferts and non-Seyferts has been carried out by Martini, J. Mulchaey (OCIW), M. Regan (STScI), and Pogge with new and archival *HST* NICMOS and WFPC2 imaging. They find that nuclear dust spirals, especially grand–design spirals associated with large–scale stellar bars, are found with *equal* frequency in Seyferts and non-Seyferts alike, suggesting that the trigger of AGN activity must occur at smaller scales (<100 pc), and is not going to be revealed by large–scale (few-kpc) structures in the host galaxies proper.

Pogge, Williams, and Mathur searched the Sloan Digital Sky Survey Early Data Release and identified 150 new Narrow Line Seyfert 1 (NLS1) galaxies among the QSO sample. Cross-correlation against the ROSAT All-Sky Survey catalog finds about half of these with the expected ultrasoft X-ray spectral indices ($\Gamma > 2$), but a number were not detected by ROSAT. A follow-up *Chandra* ACIS survey has been approved to observe the undetected Sloan NLS1s to see if their X-ray properties are distinct from the normal run of ultrasoft NLS1s.

Atomic calculations for X-ray line intensities of the Kα complex of helium-like iron by Oelgoetz and Pradhan have shown that these features may be dominated by the dielectronic satellites (DES) of the resonance line. As such, the well known Kα lines of iron in AGN may be extremely temperature sensitive and hence useful as diagnostics of ionized accretion discs, accretion flows, flares, and Kα temporal-temperature variability in AGN. As in the case of supernova 1995N, the Lyman α pumping of Fe II described by Sigut and Pradhan in 1998 was also observed, for the first time, in four narrow–line Seyfert galaxies leading to the formation of several near-IR lines at $\sim 1\ \mu$m.

Vestergaard has completed a spectroscopic program to study the narrow (FWHM $\lesssim 500$ km s^{-1}) C IV λ1549 intrinsic absorbers in a large sample of $z \approx 2$ quasars. One goal was to study their basic statistics since little is currently known about the frequency and properties of these absorbers in luminous quasars. The main results are: (1) irrespective of radio type a similar high incidence of intrinsic absorbers was found and the most absorbed quasars are systematically more dust-reddened, (2) the narrow line absorbers are relatively equatorial in origin similar to the more dramatic broad absorption line troughs seen almost exclusively in radio-quiet quasars, (3) the strongest narrow absorbers follow predictions of disk wind models in which a gaseous wind rises above the disk and at a sufficiently large altitude is pushed outwards by the radiation pressure from the central ionizing source, and (4) the data also support the expectations of these models that unlike radio-quiet quasars, the radio-louds are incapable of accelerating these absorbing clouds to high velocities ($\gtrsim 3{,}000$ km s^{-1}) due to their stronger X-ray flux.

Vestergaard is investigating the distribution of black-hole masses in the centers of high redshift ($z > 1.5$) quasars. The first results show that even at the highest redshifts ($z \gtrsim 4$) the currently known quasars have very massive ($10^8 - 10^{10}$ M$_\odot$) black holes, comparable to quasars at lower redshift. At these high redshifts the quasar host galaxies are still in the process of forming. They only contain a small fraction of their final stellar mass and have large star formation rates (between $\sim$500 and $\sim$2000 M$_\odot$yr^{-1}. This shows that black holes must form early, fast, and with little observable emission.

Vestergaard and Osmer are investigating the mass distribution of active black holes in nearby and distant quasars and how these distributions compare to inactive black holes in centers of local galaxies. The ultimate goal is to place constraints on the evolution of quasars and the growth of black holes. The latter will be done in collaboration with Steed and Weinberg.

Vestergaard, Peterson, and Mathur are continuing an investigation of the iron emission in a large sample of nearby active galaxies using data from radio through 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 project goal is to perform a systematic study of the iron emission 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 (Florida) and collaborators from Heidelberg, Vestergaard is involved in a continuing study of the metal abundances of high-redshift ($z \gtrsim 3.4$) quasars. The goal is to attempt to constrain the epoch of the early star formation in the universe by combining the relative Fe II to Mg II strength measured in high-redshift quasars with chemical evolutionary models.

Onken, Mathur, Romano, Pogge, Peterson, and J. Kuraszkiewicz (CfA) are continuing their work on the far-UV properties of narrow–line Seyfert galaxies, now analyzing *FUSE* observations of NGC 4051. This study of the intrinsic O VI absorption will help determine whether the X-ray and UV absorbers are physically related, and it will constrain models of the galaxy's photoionization near the nucleus.

9. LARGE–SCALE STRUCTURE

Weinberg, in collaboration with N. Katz (U. Mass.), R. Davé (Arizona), and others, continued a research program using cosmological hydrodynamic simulations to model the formation and clustering of galaxies and the evolution of the intergalactic medium. Highlights from this year include: predictions of X-ray forest absorption by shock-heated intergalactic gas (led by X. Chen of OSU Physics and UCSB), predictions of the correlations between the Lyα forest and Lyman-break galaxies at redshift $z \approx 3$ (led by Kollmeier), demonstration that simulated galaxy groups exhibit the observed scalings of X-ray properties, and comparison of the predicted bias of galaxies to observations of galaxy clustering and galaxy–galaxy lensing.

As a member of the Sloan Digital Sky Survey (SDSS) collaboration, Weinberg (with M. Strauss, V. Narayanan, R. Lupton, and others) completed the paper defining the survey's galaxy spectroscopic target selection algorithm and contributed to studies of galaxy clustering in the redshift survey and the distribution and correlations of galaxy observable properties. Pizagno and Weinberg, in collaboration with H. Rix and F. Prada (MPIA), are analyzing rotation curves of SDSS galaxies to study the Tully-Fisher relation and its residuals.

Zheng, Tinker, Weinberg, and A. Berlind (Chicago) have been carrying out theoretical work aimed at interpreting the SDSS galaxy clustering measurements, including calculating the dependence of the dark halo population on cosmological parameters, developing and testing schemes for breaking the degeneracy between cosmology and galaxy bias, and comparing the galaxy halo occupation distribution predicted by hydrodynamic simulations and semi-analytic models of galaxy formation.

Steed, Weinberg, and Miralda-Escudé are developing a theoretical framework for modeling multi-wavelength data on quasar luminosity function evolution. The central actor in this framework is the accretion rate distribution, which determines the evolution of the black hole mass function and, together with the black hole mass function at a given redshift, determines the quasar luminosity function. Extensions of the model allow for black hole mergers, obscured accretion, advection dominated accretion flows, and other possible complications.

Miralda-Escudé and Onken are investigating the potential contribution toward the reionization of the universe by stellar ionizing flux arising within a distribution of dark matter halo masses. The results of this work should provide limits on the relative production of ionizing radiation from non-stellar sources that is required to reionize the universe at a redshift of ~ 6.

Miralda and Zheng 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 produces simulated images and spectra of the Lyα emission line generated from either external irradiation or internal ionization and excitation. The code has been applied to oblate models of damped Lyα systems with and without rotation.

Miralda and Kollmeier are examining hydrodynamic numerical simulations of galaxy formation and the intergalactic medium that include galactic winds due to energy injection associated with star formation, to study the possible effects of galactic winds. The Lyman α forest absorption is expected to correlate with galaxies, but galactic winds may evacuate or heat the gas in the vicinity of a galaxy and hence reduce the Lyman α absorption due to the intergalactic gas that surrounds the galaxy.

Miralda is considering how the emissivity of ionizing photons is obtained from the observation of the mean decrement in the Lyman α forest (which yields the intensity of the ionizing background), and the abundance of Lyman limit systems (which yields the mean free path of the ionizing photons). This emissivity needs to remain approximately constant up to redshift $z \simeq 10$, compared to the value determined at $z \simeq 4$ from observations, in order that the intergalactic medium can be reionized by $z = 6$, as shown by the observed QSOs up to this redshift.

10. COSMOLOGY AND HIGH-ENERGY ASTROPHYSICS

Ryden has written a textbook entitled *Introduction to Cosmology*. Published by Addison–Wesley in October 2002, it is intended for use in upper–level undergraduate or graduate courses.

Scherrer continued to concentrate much of his effort on two major areas: constraints on particle physics from the cosmic microwave background (CMB) and quintessence models for the vacuum energy density. Because of a wealth of new observational data, these two areas of cosmology have become a central new testing ground for the role of particle physics in cosmology.

Walker's research interests also lie at the interface of particle physics and cosmology. In addition to continuing along the directions of past research, he has moved into using the CMB and Type Ia supernovae to constrain cosmological parameters and has begun looking at the physics of high energy cosmic rays. Walker has also started looking at Brane cosmologies, and work on the relic neutrino background from all past Type II supernovae has gained recent notoriety. This work has been done in collaboration with the students, postdocs, and faculty in the theoretical astro-particle group.

The confrontation between the predictions of primordial nucleosynthesis and the primordial abundances of the light elements inferred from observational data is the main focus of Steigman's research program. He and his collaborators continue to pursue a vigorous, multi-pronged program aimed at exploiting observational data to derive better estimates of the primordial abundances, with the goal of using such data to challenge and test the standard hot big-bang model. This effort continued with two independent projects aimed at constraining the abundances of ^{4}He and Lithium.

The recent flood of CMB observations has allowed constraints to be placed on variations in the standard model of particle physics. Scherrer, Walker, Steigman, and J.P. Kneller (OSU Physics) completed a project on the combined constraints that the CMB and primordial nucleosynthesis can place on neutrino physics beyond the standard model. Scherrer also finished a project with a former postdoc, X. Chen (U.C. Santa Barbara), and S. Hannestad (NORDITA, Denmark) on a study of strongly–interacting dark matter. They discovered that the current CMB observations can provide new constraints on the scattering cross section between dark matter and baryonic matter.

Scherrer is currently supervising two students (Jens Kujat and Angie Linn) on two separate projects involving particle physics and the CMB. Kujat is investigating constraints which can be placed on decaying particles from current CMB observations, while Linn's project is an investigation of CMB anisotropies in models with non-standard recombination histories.

Scherrer is also working in the area of quintessence models. Recent observations suggest that up to 70% of the energy in the universe may be smoothly distributed with a bizarre equation of state. In quintessance models, this energy is assumed to lie in the form of a scalar field. In collaboration with Chen and Steigman, Scherrer completed work on a study of 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 therefore sharply constrained by observations. We showed that it is possible to construct models of this type which satisfy all of the observational constraints and still lead to an interesting reduction in the primordial helium abundance.

Scherrer, Weinberg, Linn, and Kujat have examined a variety of cosmological observables to see if they could be combined to provide constraints on the equation of state of a quintessence component. They showed that while models with different equations of state are easily distinguished, it is much more difficult to distinguish models with time–varying equations of state from models with constant equations of state.

Scherrer, S.A. Raby (Physics), and B.S. Joshi (Physics) worked on a supersymmetry–motivated model for quintessence, involving three scalar fields. Scherrer is also examining the evolution of tachyon fields in the early universe; such fields have recently been proposed as a model for either the dark matter or dark energy in the universe.

Along with R. Gruenwald and S.M. Viegas (São Paulo), Steigman continued to investigate sources of potential systematic error in using emission–line observations of extragalactic H II regions to zero-in on the primordial abundance of ^{4}He. In their most recent work 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. In this study 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.

In work with Steigman's OSU collaborators Pinsonneault and Walker and V. Narayanan (Princeton), observations of Pop I stars were used in 1998 to normalize the rotational mixing of lithium from stellar surfaces, permitting limits (both lower and upper) to be set on lithium mixing in the Pop II stars which are used to infer the primordial lithium abundance. This work has now been extended 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 the depletion suggested by their models.

Scherrer, with S. Stirling (a graduate student at U. Texas), completed work on an investigation of inhomogeneous neutrino degeneracy and its effects on big-bang nucleosynthesis.

It has long been known that the light elements Li, Be and B can be synthesized in collisions between cosmic–ray nuclei and interstellar gas nuclei. For near-solar metallicities, collisions between cosmic ray protons and α–particles and interstellar CNO nuclei dominate. If, naively, the complementary reactions are ignored, a quadratic relation between the LiBeB abundances and Fe/H is "predicted," in contrast to the observed, nearly linear relation. Kneller, Steigman and Walker have shown that cosmic ray CNO nuclei hitting interstellar H and ^{4}He can dominate LiBeB production below solar metallicities, leading to a more nearly linear abundance relation in agreement — quantitatively as well as qualitatively — with the observed data.

Early epochs in the evolution of the Universe may harbor valuable clues to the nature of the dark matter/energy, but they are shrouded by the huge optical depth of the pre-recombination plasma and can only be explored indirectly through the comparisons between observations and the predictions of primordial nucleosynthesis (BBN) and of the temperature fluctuations in the spectrum of the cosmic microwave background radiation (CMB). BBN and the CMB together have the potential to distinguish among — or at least constrain — competing models for the dark energy, some of which leave the strength of gravity invariant while adding to the relativistic energy density, while others may modify both. In work by Steigman with postdoc J. Kneller (now at North Carolina State U.) modifications to the standard model BBN and CMB predictions in the presence of extra, relativistic energy ("equivalent neutrinos") are compared and contrasted for those models of "quintessence" which, during RD epochs, contribute a fixed fraction of the relativistic energy density and, for non-minimally coupled scalar fields (one of whose effects is to alter the strength of the gravitational constant G). From their joint comparison of the BBN and CMB constraints they find that there is a small window of consistency for models with extra relativistic energy and for the minimally-coupled quintessence models, but that there is a tension between the BBN and CMB constraints which make it very difficult to find an internally-consistent, non-minimally coupled quintessence model.

Steigman has used the first observations of deuterium and oxygen in the Local Interstellar Medium (LISM) obtained with the Far Ultraviolet Spectroscopic Explorer (*FUSE*) to search for local variations in their abundances. While the very limited sample of these first data may be consistent with no variations, they do offer a hint of anti-correlated variations between D/H and O/H which, if confirmed by more data, suggest that observations of interstellar gas within a few kpc of the solar neighborhood may reveal signs of the evolution of the abundance of deuterium from there and then (the Big Bang), to here and now (the Local Interstellar Medium of the Galaxy).

11. ATOMIC ASTROPHYSICS

In the last year, Herbst, F.C. De Lucia (Physics) and colleagues from the U. of Cologne, Germany have used laboratory techniques to study the rotational spectra of known and likely interstellar molecules. Much of the work is in the submillimeter-wave region of the spectrum, in preparation for astronomical results from *Herschel*. The molecules studied this year include the phosphidogen radical (PH_2), acetone, and ethyl methyl ether.

Pradhan, Nahar, Chen, Delahaye, and Oelgoetz work together in the general area of atomic physics and its implications for astrophysical problems. The studies are aimed at various problems in astrophysical spectroscopy and atomic radiative and collisional processes. They carry out accurate atomic calculations using *ab initio* quantum mechanical methods of collision strengths, photoionization cross sections, transition probabilities, and electron-ion recombination rates. The results are incorporated into astrophysical models for spectral analysis of ground and space based observations. The large−scale calculations are carried out at the Ohio Supercomputer Center in Columbus, Ohio, on a variety of computational platforms such as the Cray series and parallel clusters. Collaborators include Honglin Zhang (Los Alamos), Werner Eissner (Stuttgart, Germany), Claude Zeippen (Obs. de Paris), Aaron Sigut (U. Western Onterio), R. Phaneuf (U. Nevada), and F. Wuilleumier (U. de Paris−Sud).

The group at Ohio State constitutes the U.S. participation in the international Iron Project (IP) whose aim is to calculate atomic parameters for the astrophysically important elements, particularly the iron group. Along with other members from the UK, France, Germany, Canada, and Venezuela, the IP team is investigating collisional excitation, photoionization, and fine structure bound-bound transitions, to analyse astrophysical spectra of iron-peak elements such as iron, cobalt, and nickel which are the end-products of stellar nucleosynthesis. The work under the IP complements and improves upon the work of the erstwhile Opacity Project (OP) which resulted in the calculation of a huge quantity of radiative data for stellar opacities. The relativistic Breit−Pauli R-matrix (BPRM) method in the close coupling approximation, used in the IP work, enables highly accurate and large scale calculations for both atomic radiative and collisional processes. Recent work includes electron impact excitation collision strengths for one of the most difficult, but astrophysically important, neon−like ion Fe XVII, whose spectral features are prominent in X-ray sources (Chen & Pradhan, 2002). Collision cross sections have also been obtained for the helium−like ion O VII, another important ion in X-ray plasma diagnostics (Delahaye & Pradhan, 2002).

Photoionization cross sections of highly charged but complex ions, such as carbon−like Ar XIII, Ca XVII, and Fe XXI, have been calculated. These ions were studied under the Opacity Project in 1992. However, the present study by Nahar with larger wavefunction expansion has revealed: (i) extensive resonant features in the high energy region from the $n=3$ complex, considerably more prominent than those of the $n=2$ complex, and (ii) complex features in the large energy gap between the $n=2$ and 3 complexes. Nahar is continuing her collaboration with experimental groups at Aarhus, Reno/Berkeley, and Paris, measuring precise photoionization cross sections of single and multply charged ions in low lying states. Her theoretical cross sections, using the relativistic Breit−Pauli approximation, clearly delineate features observed experimentally. Work is near completion for O II, O III, O IV, and O V cross sections. The fine structure features in the new calculations are missing from previous non-relativistic LS data. Delahaye is studying fine structure effects in photoionization cross sections of Fe II to compare with the recent experiment at Aarhus University.

The unified method for calculating total electron−ion recombination rates, which accounts for both radiative and dielectronic recombinations in a self−consistent manner and which was developed by Nahar and Pradhan in 1994, is being used for the highly charged and complex carbon−like ions Ar XIII, Ca XV and Fe XXI. The larger wavefunction representations show multiple dielectronic recombination bumps for the first time. Over 700 LS bound states with $n \approx 10$ are found for each of these ions, and their photoionization cross sections contribute to the total recombination rates. State−specific recombination rates for all bound states are also obtained. The unified method for total electron−ion recombination was extended to include the relativistic effects by Zhang, Nahar and Pradhan in 1997. Total and level−specific recombination rate coefficients are now available for a number of highly charged ions: C IV, C V (ApJS 2000), Fe XXIV and Fe XXV (ApJS 2001), and O VI and O VII (in preparation). These data should be useful in the analysis of X-ray data from *Chandra* and *XMM−Newton*.

Calculation of accurate atomic radiative transition probabilities of bound−bound levels is one important research interest of the Atomic Astrophysices group. The most recent work is to obtain a large set of transition probabilities for Fe XVII including dipole−allowed, intercombination, and forbidden magnetic dipole and electric quadrupole and octupole transitions. The relativistic BPRM method allows calculations of oscillator strengths for a large number of allowed transitions with consistent accuracy as needed for radiative−collisional models. Nahar recently reported the relativistic fine structure transitions for 15 Li−like ions from carbon to nickel. Work is complete, or in progress, for a number of ions, such as S II, O II, O III, O IV, Ne IV, and helium–like ions such as C IV, N V, O VI, etc.

Highly charged ions are being observed in the X-ray spectra taken by *Chandra* and *XMM–Newton*. The Kα lines, due to 1s–2p transitions, give rise to resonance complexes in all ionization states of an element. Kα resonance strengths in all ionization states of oxygen have recently been calculated. Cross sections for He– and Li–like O VI and O VII have also been calculated by Nahar and Pradhan. Pradhan showed a new way of analyzing these lines by calculating the the 'resonance oscillator strength' $\overline{f}_r$ 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 *et al.* have predicted such lines for Li–like C IV and Fe XXIV. Work is in progress for X-ray line detection for the oxygen isonuclear sequence of ions.

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