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This report covers the period September 1998 through August 1999 and comprises an account of astronomical research carried out in the Department of Astronomy and the Department of Physics.

Faculty and Research Associates were James Applegate, Elena Aprile, Norman Baker, William Craig, Arlin Crotts, Karl-Ludwig Giboni, Eric Gotthelf, Charles Hailey, Jules Halpern, David Helfand, Stephen Kahn, Marc Kamionkowski, Laura Kay (Barnard), Karen Leighly, Lloyd Motz (Emeritus), Reshmi Mukherjee (Barnard), Robert Novick (Emeritus), Frederik Paerels, Joseph Patterson, Kevin Prendergast, Andrew Rasmussen, Malvin Ruderman, Daniel Savin, Edward Spiegel, Marco Tavani, Wilhelmus van der Veen, and Jacqueline van Gorkom.

Lam Hui joined the faculty of the Physics Department in July 1999. Carmen Marcella Carollo joined the faculty of the Astronomy Department in September 1999.

The American Museum of Natural History has established an Astronomy Department, and two of its members, Michael Shara and Mordecai-Mark MacLow, hold Adjunct appointments in the Columbia Astronomy Department.

Graduate students participating in research were Elizabeth Blanton, Ari Buchalter, Tzu-Ching Chang, Xuelei Chen, Xinzhong Chen, Jean Cottam, Alessandro Curioni, Akimi Fujita, Mario Jimenez-Garate, Ming Feng Gu, JaeSub Hong, Miranda Jackson, John Keck, Tomotake Kozu, Yuexing Li, Kaya Mori, Nestor Mirabal, Don Neill, John Peterson, Jacob Noel-Storr, Masao Sako, Edgar Smith, Joshua Spodek, Ben Sogerman, John Tomsick, Robert Uglesich, Leven Wadley.

Undergraduates participating in research were Arindam Chatterjee, Mark Dijkstra (Groningen), Elliott Eggleston, Justin Detray, Irina Feygina (Barnard), Susan Kassin, Miriam Krauss, Yong Moon, Scott Schnee, Nigel Singh (Cornell), Dana Stern (Barnard), Lucianne Walkowicz (Hopkins), and Vanessa Yuille (Barnard).

Elizabeth Blanton, Ari Buchalter, Xuelei Chen, Edgar Smith, and John Tomsick received Ph.D. degrees.

Appointments during 1998–99 were held by Adjunct Professor Michael Allison, Postdoctoral Research Scientists Ehud Behar, Fernando Camillo, Valeri Egorov, Christian Knigge, Uwe Oberlack, Stephen Lawrence, Frank Summers, Louis Tao, Limin Wang, Ion Yadigaroglu.

Tsvi Piran and Reuben Thieberger held visiting appointments. Licia Verde and Raul Jimenez visited Columbia from Edinburgh.

Van Gorkom continued as Chair of the Astronomy Department. Paerels was appointed Director of the Columbia Astrophysics Laboratory replacing Kahn who resigned to become Chair of the Physics Department.

1. STARS & STELLAR EVOLUTION

Lawrence and Crotts have detected the far ultraviolet light echo of the initial shock breakout flux from the surface of SN 1987A's progenitor being destroyed. In particular, they are using satellite observations from *IUE* and *UIT*, with recent results from *IUE* spectra showing a reflected spectrum with a steep wavelength dependence with a power law index of about -7.5 in f_λ . They have combined models of the shock breakout spectrum of the supernova during the first few days with models of a wide variety of dust parameters, attempting to reproduce the observed *IUE* spectrum. The only successful models incorporate extremely small, silicate-dominated dust grains.

Van der Veen in collaboration with several European investigators is reducing and analyzing 90 and 160 μ m images of seven evolved mass losing stars obtained with the *ISOPHOT* instrument aboard the *ISO* satellite. For five sources we have data at 90 and 160 micron, for one source only at 90 micron and for another one only at 160 micron. The images are roughly 15×35 arcmin in size and show the distribution of dust as lit up by the central mass losing stars. This inner parts of the shells are clearly detected out to at least 5-10 arcmin. There is faint emission at larger distances but it is not yet clear how far out we are able to detect this dust emission. We are currently developing strategies to measure reliably the very faint emission of the outer dust shells.

2. X-RAY & Γ -RAY SOURCES

At low Galactic latitude, the identity of majority of the *EGRET* sources is a continuing mystery. Halpern and Helfand are attempting to identify several *EGRET* sources at low to intermediate Galactic latitude by covering their error circles with *ROSAT* HRI and VLA pointings. If these sources are pulsars, then they might have faint X-ray counterparts and/or steep-spectrum radio counterparts in blank optical fields. However, they may also represent a new class of Galactic object, or perhaps blazars that are relatively radio-quiet, in which case they could also be identified using this multiwavelength approach. X-ray observations of five *EGRET* fields have been obtained, and the optical identifications of the detected sources in three of these fields are almost complete. At least one possibly interesting identification is being pursued.

Halpern and Mirabal are also examining the brightest unidentified *EGRET* source at high latitude, 3EG 1835 + 5918. Multicolor optical imaging of its entire error circle and spectroscopy of ultraviolet excess candidates at the MDM Observatory have revealed several quasars. X-ray observations of this region have also been obtained. Complete identification of these sources reveals no blazar or pulsar candidate. 3EG 1835+5918 is therefore more problematic physically than Geminga, which is an ordinary pulsar that only lacks radio emission. As a pulsar, 3EG 1835+5918 would have to be

either older or more distant than Geminga, and probably an even more efficient γ -ray engine.

The MDM Observatory continues to pursue optical afterglows of γ -ray bursts (GRBs). The most energetic event of January 23, 1999 was observed several times, and the first observation of steepening of an afterglow light curve was thereby obtained by Yadigaroglu & Halpern. Evidence for jet-like beaming of GRBs was thus found for this event, and also for GRB 980519 as described in a pair of papers by visitor T. Piran (Hebrew University, Jerusalem), Halpern, and additional collaborators. Observations of additional bursts were conducted by J. Kemp while at CTIO. A continuous update of observations of GRBs at MDM Observatory is maintained at <http://www.astro.columbia.edu/groupresearch.html>.

Helfand, in collaboration with E. Moran (Berkeley) and M. Lehnert (Leiden) completed their analysis of X-rays from the luminous starburst galaxy NGC 3256. They conclude that the hard X-ray component of the galaxy's emission is consistent with inverse Compton emission from the scattering of the copious far-IR photons off the radio-emitting electrons. They go on to use the 5 GHz to 5 keV flux ratio for such starbursts, along with the radio source counts to faint flux densities, to estimate the contribution of these galaxies to the cosmic X-ray background. They find that 10% to 30% of the background could arise from starbursts. In a complementary project, Helfand and Moran have been using data on high-mass X-ray binaries in the Local Group to estimate the contribution of such systems to the hard X-ray flux of a starburst population. They find that only 20% to 40% of the observed 2-10 keV flux from the half dozen starbursts observed with ASCA can be readily explained by Pop I X-ray binaries. Contributions from an AGN, inverse Compton emission, or some other process is required to explain the total high-energy output of these galaxies.

Sako, Kahn, Paerels, and Liedahl (LLNL), are involved in a quantitative analysis of the X-ray spectrum of the eclipsing high mass X-ray binary Vela X-1 (4U 0900 – 40) using archival data from the ASCA Solid-State Imaging Spectrometer. The spectrum observed during eclipse exhibits two distinct sets of discrete features: (1) recombination lines and radiative recombination continua from mostly hydrogenic and helium-like species produced by photoionization in an extended stellar wind; and (2) fluorescent K-shell lines associated with near-neutral species also present in the circum-source medium. These features are superposed on a faint continuum, which is most likely nonthermal emission from the accreting neutron star that is scattered into our line of sight by free electrons in the wind. Using a detailed spectral model that explicitly accounts for the recombination cascade kinetics for each of the constituent charge states, we are able to obtain a statistically acceptable ($\chi_r^2 = 0.88$) fit to the observed spectrum and to derive emission measures associated with the individual K-shell ions of several elements. From calculations of the ionization balance using the photoionization code, XSTAR (Kallman & Krolik 1995), we assign ionization parameters, ξ , to several ions, and construct a differential emission measure (DEM) distribution. The DEM distribution spans a broad range in ξ ($\Delta \log \xi > 2$), and is

centered around $\log \xi = 2.5$. We find that the total emission measure of the visible portion of the highly ionized wind is $\sim 3 \times 10^{56} \text{cm}^{-3}$. The qualitative aspects of the inferred DEM distribution are consistent with a wind model derived from the Hatchett & McCray (1977) picture of an X-ray source immersed in a stellar wind with a generalized Castor, Abbott, & Klein (1975) velocity profile. Using this formalism, theoretical DEM distributions, parameterized only by a mass loss rate and a wind velocity profile, are calculated and used to predict the detailed X-ray spectrum, which is then compared to the ASCA data. Again, we find a statistically acceptable fit ($\chi_r^2 = 1.01$), with a best-fit mass loss rate of $\sim 2.7 \times 10^{-7} M_{\odot} \text{yr}^{-1}$. This is approximately a factor of 10 lower than previous estimates of the mass loss rate for the Vela X-1 companion star, which have primarily been determined from C IV and Si IV P Cygni profiles, and X-ray absorption measurements. We argue that this discrepancy can be reconciled if the X-ray irradiated portion of the wind in Vela X-1 is structurally inhomogeneous, consisting of hundreds of cool, dense clumps embedded in a hotter, more ionized gas. Most of the mass is contained in the clumps, while most of the wind volume ($> 95\%$) is occupied by the highly ionized component. This interpretation is also quantitatively consistent with the presence of the X-ray fluorescent lines in the ASCA spectrum, which are produced in the cooler, clumped component.

Sako, Kahn, Paerels, Liedahl (LLNL), and Wojdowski (LLNL) are performing an orbital phase-resolved spectral analysis of Centaurus X-3 as a follow-on to the ASCA analysis of Vela X-1. The companion star of Cen X-3 is an O-star with an inferred mass loss rate of a few $\times 10^{-6} M_{\odot} \text{yr}^{-1}$. In contrast to Vela X-1, Cen X-3 is a high-luminosity system where a simple Bondi-type accretion from the stellar wind cannot account for the observed luminosity, and this discrepancy is attributed to the presence of an accretion disk. We find that X-ray emission from photoionization of a normal radiatively-driven wind cannot reproduce the orbital phase variability of the emission lines. We believe that the X-ray continuum radiation from the neutron star creates a radiatively-driven wind from the irradiated surface of the companion star. A more detailed analysis is in progress.

Sako, Kahn, Paerels, and Liedahl (LLNL), are performing a detailed spectral analysis of the ASCA archival data of the Circinus Galaxy. The spectrum shows numerous emission lines in the soft X-ray band from highly ionized ions, as well as Compton reflection and fluorescent lines from neutral or near-neutral matter. We analyze the spectrum in the context of a self-consistent recombination cascade model and find that a nearly flat DEM distribution fits the data. For a spherically symmetric distribution of matter surrounding a point source, this corresponds to a run on density of the form, $n(r) \sim r^{-3/2}$. Using this density profile and comparing the resulting emission spectra with the ASCA data, we estimate the size of the X-ray emission line region to be $\sim 260 \text{pc}$. This value is consistent with the spatial extent seen in the ROSAT HRI image of this object.

Mukherjee, together with other scientists, observed TeV gamma-rays from astrophysical sources using STACEE (Solar Tower Air Cherenkov Effect Experiment), located at Al-

buquerque, New Mexico. STACEE is a ground-based gamma-ray detector that is sensitive to the energy range between 25 and 500 GeV. This part of the electromagnetic spectrum has been largely unexplored, and STACEE has the potential for filling an important niche in high energy astrophysics. STACEE reported the detection of the Crab nebula at around 100 GeV, one of the first reported detections at this energy.

Mukherjee together with David Hanna of McGill University (and currently a Visiting Scholar at the Columbia Astrophysics Lab) designed and installed a laser system for STACEE, which was used for calibration monitoring of the components of STACEE during the 1998 October to 1999 April observing period.

Mukherjee, Gotthelf, Dana Stern and Tavani worked on unidentified EGRET sources, specifically the two sources near the COS-B gamma-ray source 2CG 075+00. In addition, Mukherjee worked on spectral analysis of several active galaxies observed by EGRET.

During Piran's stay at Columbia University he has worked mostly on Gamma-Ray Bursts. The highlights of this research were the prediction of a prompt optical afterglow that should accompany GRBs (this afterglow was later discovered for GRB 990123), and the discovery of jets and beamed emission in GRB 990123 and GRB 980519. The following is an outline of the outcome of this research.

During the early fall of 1999, Piran has worked (together with Re'em Sari) on the early afterglow from GRB. By early afterglow is meant afterglow that is simultaneous or just a few seconds after the burst. We have calculated the Gamma-ray and X-ray light curves. These come from the forward shock that arises when the relativistic ejecta begin to be slowed down by the ISM. We have also noticed that the reverse shock that arises at the same time will give rise to a very strong optical emission. We have presented these results in the Rome meeting in late October 1999 (*A&A* to be published) and in a more detailed work that will be published in *Ap.J.*. A short time later ROTSE discovered such emission from GRB 990123. Piran is a co-author of one of the observational discovery papers of the afterglow of this GRB and he has written, again with Sari, an *Ap.J. Letter* analyzing the early observations of this burst.

In the observational paper of GRB 990123 we noticed that there is a break in the light curve of this burst, and interpreted this as a beaming break. Such a break should arise if the emission is beamed when the Lorentz factor of the ejecta reaches the value $1/\theta$, where θ is the beaming angle. This was the first observation of such a break. In another paper we outlined the theory of beamed emission from GRBs and applied it to several bursts and in particular to GRB 980519, for which we argued that even without seeing the break we can infer that it has occurred from the late-time light curve and spectra. In an accompanying observational paper we have estimated the light curve and spectra of the afterglow of GRB 980519.

Piran has finished a large review paper on GRBs that has appeared in *Physics Reports*. In other work concerning GRBs he has studied the images, light curves and spectra of GRB afterglow and has examined the observational conse-

quences of refreshed afterglows – by this we mean afterglows that are enhanced due to late acceleration by new fresh ejecta.

He also worked (with H. El Ad, with Y. Friedman and with Tzu-Ching Chang) on various implications of voids in the Galaxy distribution. We are in the final stages of an observational paper comparing voids in the IRAS catalogue and in the ORS catalogue (with H. El Ad) and on a theoretical paper on formation of Voids with (Y. Friedman).

3. RADIO ASTRONOMY

Helfand and his principal collaborators, R. Becker (UC Davis) and R.L. White (STScI), completed another VLA observing session for the FIRST survey. To date, over 6000 deg² have been mapped at 5" resolution and over 550,000 radio sources have been located to subarcsecond accuracy. All these data, along with a description of the current survey status, are available at the FIRST website <http://sundog.stsci.edu>.

In collaboration with R. McMahon (Cambridge), the FIRST team completed a match of their radio catalog with the Automated Plate Machine (APM) scans of the POSS-I plates. Prior to this work, fewer than 500 radio-selected objects in the flux density range 1-30 mJy had *suggested* optical counterparts; the new results, to be published in the *ApJ* and on the Web next year, contains over 70,000 optical identifications, 18% of all radio sources in the FIRST survey region. As part of this project, an improvement of nearly an order of magnitude in the astrometric accuracy of the POSS-I plate scans has been achieved through comparison with the precise radio positions.

As part of the FIRST Bright Quasar Survey, Helfand, White, and Becker have created a decision tree algorithm that can predict with 95% accuracy whether or not an optical counterpart to a FIRST source is a quasar/BL Lac or not. This work will soon appear, along with the results of 60 nights of spectroscopic followup of FIRST counterparts which has led to the identification of over 700 quasars and BL Lacs brighter than $R = 17.8$ in the initial 2600 deg² of the FIRST survey. In addition to the discovery of the first radio-loud Broad Absorption Line quasars and a higher than normal frequency of lensed objects, one of the survey's interesting results is that the distribution of radio loudness in this sample *peaks* at the minimum in the current bimodal distribution for quasars; i.e., we see no evidence at all for two separate populations of quasars based on radio-to-optical flux ratio.

Helfand has also led an effort involving Yadigaroglu and his FIRST collaborators to assess the requirements for a Catalog of Bright Extragalactic Astrometry Standards for the Space Interferometry Mission (SIM). The extreme requirements imposed on SIM targets (no extent greater than 1 mas and photocenter stability at the μ arcsec level) means that a large, all-sky catalog of bright quasars is needed, and techniques to winnow out extended, variable, and other unsuitable candidate targets are required. The decision tree algorithm discussed above can be used to extend the FBQS to the areas of the sky covered by the NRAO VLA Sky Survey and the Sydney University Molonglo Sky Survey (both of which

have an order of magnitude worse spatial resolution), achieving a spectroscopic followup efficiency sufficient to extend the bright quasar survey to 4π steradians. High-resolution optical, near-IR, and radio imaging of the objects discovered are then being used to select the most promising candidates for SIM observations.

4. PULSARS & NEUTRON STARS

Camillo, with collaborators Halpern, Helfand and Gotthelf has been working in the continuing Parkes Multibeam Pulsar Survey, already the most successful pulsar survey ever with the discovery of over 450 pulsars. He is also studying the globular cluster 47 Tuc, where at latest count we know of 22 millisecond pulsars. Future plans include the follow-up study of some of these sources with synthesis radio telescopes, and at optical and X-ray wavelengths.

Halpern is studying rotation-powered pulsars with *ASCA* and *AXAF* in collaboration with G. Pavlov (Penn State U.). Long observations of several key targets have been obtained to study phenomena such as the spectrum of a neutron star atmosphere, and the spectrum and pulse profile of a millisecond pulsar. These new observations are necessary to disentangle thermal and nonthermal processes that may be present in the same object, and to correctly derive quantities such as the effective temperature of the neutron star surface, the luminosity of a heated polar cap, and the M/R relation of the neutron star. One of these targets is the nearest millisecond pulsar, PSR J0437–4715.

Gotthelf is studying several X-ray sources at the centers of supernova remnants in order to understand the evolution of young neutron stars and their relationship to supernovae. Gotthelf, G. Vasisht (JPL/Caltech), and T. Dotani (ISAS, Japan) confirmed that 1E 1841–045, the 12-s anomalous X-ray pulsar (AXP) which lies at the center of the supernova remnant Kes 73, is spinning down at a remarkably rapid pace. The spin-down rate and flux are exceptionally stable; these findings all but eliminate an accretion origin for the X-ray emission and strongly favor the “magnetar” model, with an enormous implied magnetic field of 7×10^{14} Gauss. Along with D. Chakrabarty and V. Kaspi (MIT), Gotthelf and Vasisht are implementing a monitoring campaign for the Kes 73 pulsar with *RXTE* in order to obtain a phase-connected timing solution. The new data will be highly sensitive to glitches, outbursts, and other timing noise.

A long-term study was also undertaken of the central X-ray source in the SNR RCW 103. Gotthelf, R. Petre (NASA/GSFC) and Vasisht discovered variability of 1E 161348–5055 by up to an order of magnitude in the hard 3 – 10 X-ray band. This further refutes the long-standing claim of a cooling neutron star as the source of the emission, and provides a natural explanation for difficulties encountered in reproducing the original *Einstein* X-ray detection.

Gotthelf, Vasisht, B. M. Gaensler (MIT), and K. Torii (Osaka U.) continue their study of AX J1845–0258, a 7-s *ASCA* pulsar which strongly resembles AXPs. A dedicated VLA search at 5 and 8 GHz, centered on the location of the pulsar, revealed a previously unknown young ($\approx 8,000$ yr-old) supernova remnant, G 29.6+0.1. Newly acquired *ASCA* data confirm a dramatic reduction in X-ray flux from

the pulsar and reveal a faint X-ray point source, AX J184453.3–025642, within the pulsar’s error circle. This X-ray source is surrounded by a partial shell of emission coincident with the radio remnant.

Gotthelf, Gaensler, Kaspi, and M. J. Pivovarov (MIT) have made an X-ray study of the young rotation-powered radio pulsars PSR B1046–58 and PSR B1610–50 using archival data. They evaluated previous claims of large ($\sim 10'$) diffuse nebulae surrounding these objects, and found that the apparent nebulosity could be explained completely as image artifacts in both cases.

5. GALAXIES

Crotts, Uglesich, Gould (Ohio State U.), Gyuk (UC San Diego), Kuijken (Kapteyn), Sackett (Kapteyn), Sutherland (Oxford), Tomaney (U. of Washington) and Widrow (Queens U.) - the MEGA consortium - have begun a multi-year series of observations at several telescopes using wide-field CCD imagers in order to track stellar variability and gravitational microlensing among most of the stars in M31. By the end of the project they should be able to say to what extent dark matter in spiral galaxy haloes is composed of massive, condensed objects, and what the spatial and mass distributions of such objects are. In addition there are several interesting investigations using cepheids, miras, eclipsing variables and other variable stars in M31.

Van Gorkom investigates the evolution of galaxies and the growth of large scale structure by HI imaging of the gaseous component of galaxies in different environments and by mapping out the distribution of gas-rich and possibly light-poor galaxies on larger scales.

A big project is to study the structure of clusters in the local universe. This year data were obtained for several clusters. Fujita, van Gorkom and Verheijen (NRAO) imaged Abell 85 with the VLA, while Uson (NRAO) and van Gorkom continued their observations of Abell 2029. Abell 85 is an ongoing or recent merger between two groups, while Abell 2029 is one of the dynamically most relaxed and richest clusters in the nearby universe. Both clusters turned out to be surprisingly HI deficient, more so than any cluster imaged so far. For the first time ever an attempt was made to image in HI a cluster at $z = 0.2$. Szomoru (UCSC), van Gorkom and Poggianti (Padova) obtained data on Abell 963 with the Westerbork Radio Synthesis Telescope. Analysis is still under way.

Two papers on the substructure in clusters as evidenced from the distribution of gas-rich and gas-poor galaxies were submitted for publication. Valluri (Chicago), van Gorkom and McMahon analyzed Hydra, while Bravo-Alfaro (Guanaajuato), Cayatte, Balkowski (both Meudon) and van Gorkom analyzed Coma. Fujita and van Kampen (Edinburgh) used a semi-analytic modelling code, to investigate the effect of ram pressure stripping in clusters on the evolution of galaxies.

On smaller scales Wilcots (Madison), van Gorkom, Zabludoff (Univ. of Arizona), Mulchaey (Carnegie Obs) and Williams (Univ of Delaware) have started a program to do deep HI mosaicing of loose groups of galaxies in different dynamical states. The first group, NGC 5846, looks some-

what like a mini cluster with no HI detections within 250 kpc from the central galaxies. Further out tiny HI masses were detected.

An HI survey of elliptical galaxies without optical fine structure was analyzed by Dijkstra and van Gorkom. The goal was to see whether these galaxies differed in their HI properties from galaxies with shells, which had been previously studied by Schiminovich and van Gorkom. There is no difference in HI detection rate, morphology and kinematics between shell and non shell ellipticals. Whether an elliptical has HI or not appears to be mostly determined by the environment it is in.

6. ACTIVE GALACTIC NUCLEI

Leighly continues her studies of the subclass of AGN known as Narrow-line Seyfert 1 galaxies (NLS1s). Two papers on the X-ray variability and spectral properties obtained from *ASCA* data were accepted for publication in *Ap. J. Suppl.* In collaboration with J. Siebert, D. Grupe (MPE, Garching), and others, Leighly has made progress in understanding radio-loud NLS1s. *HST* ultraviolet spectra of two NLS1s with interesting X-ray properties were obtained, and a paper on the results is in preparation.

Leighly completed various other investigations of Seyfert galaxies: An *RXTE* observation of the nearby galaxy NGC 6300 revealed the flat photon index and huge equivalent width iron line characteristic of a Seyfert 2 galaxy (Leighly *et al.* 1999). Spectropolarimetric properties of two highly polarized Seyfert 1 galaxies were presented, in collaboration with Kay, Halpern and M. Magalhães (IAG/USP, Brazil), at the 1999 winter AAS meeting, and a paper is in preparation. Optical and X-ray data from a soft X-ray transient AGN have been published (Grupe *al.* 1999). Analysis of the *RXTE* data from the ultraluminous IRAS galaxy NGC 6240 has been completed (Ikebe *et al.* 1999).

Jackson has been working with Leighly on two *RXTE* projects. One involves analysis of ten simultaneous *RXTE* and *ASCA* observations obtained over one month of the luminous Seyfert 1 galaxy Mrk 509. The other consists of a comparison of the ongoing *RXTE* monitoring observations of the broad-line radio galaxy 3C 390.3 with the results of a year-long campaign on the luminous Seyfert 1 galaxy Fairall 9 obtained in 1997.

Halpern and M. Eracleous (Penn State U.) are continuing their long-term spectroscopic monitoring of very broad, double-peaked Balmer lines, which are found preferentially in radio-loud AGNs. The profiles of these double-peaked lines are highly variable on time scales of months to years, a behavior which can be exploited to evaluate models for their origin, and to study the dynamics of the accretion process in AGNs. Their recent work demonstrates that variability of the shapes of the emission lines must be due to dynamical motions, and cannot be explained by reverberation (light echo) effects. They also rejected the binary broad-line region hypothesis, and scenarios involving bloated stars or “clouds” in randomly inclined Keplerian orbits. Possibly cyclic behavior in several objects appears to favor dynamical or wave motions in the accretion disk as the cause.

7. GALAXY FORMATION AND COSMOLOGY

Crotts and Bechtold (U. of Arizona) have completed a sample of absorption spectroscopy from sixteen close QSO pairs (with angular separations less than about 3 arcminutes). This will be highly useful in constraining the shape and size of QSO absorption-line objects, and determining how they cluster in the transverse direction. A comparison of transverse versus radial clustering of Lyman alpha forest absorbers has been proposed recently as a possible test of a non-zero cosmological constant Λ , and this sample of spectra may be large enough to perform this test. Additionally, Crotts, Fang, Borra (Laval U.) and York (U. of Chicago) have placed further constraints on the shape of Lyman alpha forest absorbers by observing three close triplets of sightlines to QSOs close to each other on the sky.

Buchalter and Kamionkowski calculated the three-point correlation function for galaxy redshift surveys. They studied how various bias scenarios can be disentangled by the three-point correlation function. With Jaffe (Berkeley) they carried out the first complete calculation of the projected angular correlation function. These predictions are suitable for comparison with measurement of the three-point correlation function from surveys such as the APM and *FIRST*.

Kamionkowski and Kosowsky (Rutgers) wrote a review article for *Annual Reviews of Nuclear and Particle Science* on the cosmic microwave background (CMB) and particle physics. Kamionkowski, Wang, and Jaffe calculated the detectability of several CMB polarization signals in a variety of hypothetical experiments. They showed that the amplitude of the polarization signal can be predicted in a model-independent way given the measured temperature anisotropy at degree angular scales and the baryon density predicted by big-bang nucleosynthesis. Lue, Wang, and Kamionkowski showed how parity violation from new high-energy physics could conceivably produce an observable signature in the CMB.

Xuelei Chen and Kamionkowski calculated the CMB temperature/polarization power spectra expected in alternative-gravity theories. They have generalized standard cosmological perturbation theory (in both Newtonian and synchronous gauge) to arbitrary scalar-tensor gravity theories. They then modified existing numerical Boltzmann codes to handle these alternative theories.

With Verde and Heavens (Edinburgh), Wang and Kamionkowski showed that the CMB will eventually provide a better probe of primordial non-Gaussianity than galaxy surveys for a very broad range of non-Gaussian structure-formation theories often considered. Wang and Kamionkowski showed that if inflation produced adiabatic density perturbations, then any non-Gaussianity in the primordial density distribution should be undetectably small.

Wang has been carrying out detailed investigations of quintessence models. He has surveyed a wide variety of cosmological observations in order to constrain the quintessence parameter space. He has developed “tracker-field” models for quintessence. These models provide a natural explanation for why the quintessence energy density should be comparable to the matter density today.

8. OTHER THEORETICAL INVESTIGATIONS

Fluid Dynamics. To understand better the possible occurrence of turbulence in nonmagnetized disks, Tao and Spiegel have considered the onset of motions in linearly stable swirling flows of the Taylor-Couette style. Tao has performed a numerical bifurcation study in subcritical Taylor-Couette flow by computing finite-amplitude solutions of the Navier-Stokes equation. Since the basic flow is linearly stable for all Reynolds numbers, it is difficult to obtain nonlinear solutions without a starting solution with linear instability. The approach is to impose a temperature difference across the cylinders to induce a convective instability. Once nonlinear flows are initiated in this way, they could be followed as the Rayleigh number of the heating is tuned down to remove the convective instability. Two-dimensional solutions were thus obtained in the form of nonlinear traveling waves for the case where there is no linear instability. The existence of these solutions is related to the experimentally observed transition to turbulence. The next step in this approach is to extend the computations to the case of Keplerian swirls.

A little-studied aspect of instability in shearing flows is the influence of accretion, the analogue of which in classical fluid dynamics is suction. This feature of fluid dynamics is of interest in drag reduction where the study of swirling flows with suction preceded that of disk accretion. C. Doering and R. Worthing (Ann Arbor) together with Spiegel have studied the rate of viscous energy dissipation in a shear layer of incompressible Newtonian fluid with injection and suction on the respective boundaries by means of exact solutions, nonlinear and linearized stability theory, and rigorous upper bounds. For strong enough suction a steady laminar flow is nonlinearly stable for all Reynolds numbers. For a narrow range of small suction rates, the laminar flow is linearly unstable at high Reynolds numbers. For both the laminar and turbulent flows, the energy dissipation rate becomes independent of the viscosity for high Reynolds numbers as is usually assumed for astrophysical accretion flows, as in Kolmogorov's theory of turbulence. The results have been submitted to the *Physics of Fluids*.

X. (Jon) Chen and Spiegel have continued their attempt to devise a usable form of the radiative viscous stress tensor that does not suffer from the limitation to small photon mean free paths that is a drawback of the usual forms for this tensor. They are preparing for publication a version in the theory in which the RVST is the solution of linear partial differential equation in spacetime. The result is supposed to be uniformly valid for short and long photon mean free paths.

Spiegel has been collaborating with S. Talon (Montreal) and F. Paparella (Woods Hole) on a scheme to treat semi-convection in stellar cores. The procedure is to develop the equations for small Prandtl and Lewis numbers. The resulting reduced equations are relatively tractable and they are proposing to solve them by Galerkin methods.

9. LABORATORY ASTROPHYSICS & INSTRUMENT DESIGN

Aprile, Curioni (graduate student), Egorov, Giboni, Oberlack, and Ventura (INFN-Padova University, Italy), have worked on the Liquid Xenon Gamma-Ray Imaging Telescope (LXeGRIT) project to prepare the instrument for a new balloon flight, with improved trigger electronics, data acquisition system and flight data transfer and on-board storage. The telescope images cosmic gamma-rays in the range of about 0.3 to 30 MeV through their Compton interactions in a liquid xenon time projection chamber (LXeTPC). This homogenous detector is position-sensitive in all three dimensions, providing the capability to greatly reduce background, the main limitation to sensitivity in this energy range. The LXeGRIT experiment, which is a collaboration between Columbia University (P.I. institution), Waseda University in Japan, the University of New Hampshire, and NASA/MSFC, was successfully flown on May 7, 1999, from Fort Sumner, NM. During the 9.5 hour balloon flight a total of about 200,000 events were collected, the majority at an average atmospheric depth of 4.5 g/cm². After a picture perfect launch by a 29 million cubic-foot balloon at 7:26h local time, LXeGRIT reached a float altitude of 39 km by about 10:00 am. At 5:05 pm, the payload was cut down and recovered in good conditions, a few hours later, near Fairview, Oklahoma. The goal of the flight was to study the background of this new gamma-ray detector in a high radiation environment and to verify its imaging performance and unique background rejection capabilities with observations of the Crab nebula, which was well in the telescope's 80 degree (FWHM) field-of-view (FOV) for most of the time afloat. The entire instrument, including the liquid xenon imaging detector, its liquid nitrogen cryogenics system, the active NaI(Tl) and plastic scintillator shields, the 130 channels of detector analog and digital electronics and its data acquisition systems, worked as expected. Telemetry at 1 Mbps and on-board data storage ensured full data-taking efficiency. Analysis of the flight and source calibration data is in progress. Preliminary results, presented at the 5th Compton Symposium, show that the main science goal of the May 99 flight has been achieved. The payload is back at the Columbia Astrophysics Laboratory, where it will be refurbished in preparation for a future flight of longer duration, possibly from the Southern Hemisphere. With its large FOV and good sensitivity in a broad energy band, LXeGRIT is well suited for imaging observations of compact sources in the Galactic Center and bulge. Among the science goals of such flight will be a study, for the first time with an imaging telescope, of the positron annihilation line and continuum emission. Spectral and Compton imaging analysis of the recent flight data is in progress and will provide important feedback for future observations of MeV sources with LXeGRIT. More information and pictures of the detector and the flight campaign can be found at <http://www.astro.columbia.edu/~lxe/lxegrit>. Along with a continuation of a flight program with LXeGRIT, as proposed in their NASA High Energy Astrophysics SR&T research program for the next three years, the efforts of the Columbia team will also include a research and development program on a "warm" liquid xenon TPC, to improve the spectro-

copy performance of this detector approach towards a next generation Compton telescope for a sensitive nuclear-line astrophysics mission.

Crotts is constructing a large CCD imager (8192 by 8192 pixels) for use at MDM Observatory. The first test run in August 1999 of most of the subsystems was successful, and completion of the system is scheduled for November 1999. The field of view of the imager will be a square 25 arcminutes on a side on the 2.4-meter and 45 arcminutes on the 1.3-meter telescope. Many investigations are planned using this instrument and the excellent imaging conditions, especially on the 2.4-meter.

Hong, Keck, Craig and Hailey are working on analysis of data from a balloon flight of the gamma-ray arcminute telescope imaging system (GRATIS) from Alice Springs, Australia. They are concentrating on data from the compact sources 4U1700 and GRS1758. Keck is additionally working to improve models for background simulation from balloons using published data from other balloon flights as well as the radiation transport code COG. The results from all this work should be published in the next 4 months.

Hong, Craig and Hailey continue to work on neutron shields for gamma-ray astronomy. A series of experiments using a monochromatic neutron beam source have been used to test various shielding geometries and to compare the experimental results with neutron and gamma-ray transport simulations. Hong is examining the implications of this work for future gamma-ray survey missions such as *EXIST*, and for potential impact on calorimeters in high radiation environments such as the Constellation-X satellite mission.

Neill, Craig and Hailey are analyzing data taken with the Automated Multiobject Spectrograph (*AMOS*) at the 3-meter telescope at Lick Observatory. They have prepared a paper for *Ap.J.* on Abell 262 with their collaborators at UC Santa Cruz in which they address the beta-problem. In the paper they examine velocity dispersion profiles for various galaxy populations. Combining this large and accurate data set with new analysis of *ROSAT* and *ASCA* data they have reanalyzed the beta problem in Abell 262 and shown that a previous suggestion that the beta problem is solved by excluding late type galaxies is not correct. They also discuss the implications of the beta problem for cosmology. The same group, along with Will Serber, are well along in analyzing close to 100 optical spectra obtained on the SNR IC443 using the 3m telescope.

Gu, Neill and Hailey are working on an analysis of how the recently discovered temperature dependence of cluster gas profiles affects the determination of Ω_0 obtained using the Press-Schechter formalism. They are also analyzing extant X-ray cluster data to determine how the value of Ω_0 would be modified if new models of non-radial modes in cluster formation are accounted for.

Jimenez-Garate, Craig and Hailey, along with collaborators at CalTech and the Danish Space Research Institute, are working on the development of hard X-ray focussing optics using thermally slumped glass for the high energy focussing telescope (*HEFT*) balloon payload and for the Constellation-X satellite mission. They have taken the first hard X-ray images ever using a prototype telescope and ob-

tained 40 arcsecond resolution at 8, 28 and 68 KeV. The lightweighted optics, which use a totally novel mounting scheme, are 3 times better than the state-of-the-art lightweighted soft X-ray optics of the *Astro-E* mission. The Columbia team is also working on the construction of the gondola and the pointing system for the *HEFT* payload.

Kaya Mori and Hailey are working on the spectroscopy of isolated neutron stars in anticipation of data to be obtained after the launch of XMM. They are developing appropriate models for the analysis of data from neutron stars with and without strong magnetic fields. This work is being done in conjunction with Lawrence Livermore National Laboratory.

Mori and Hailey have also published an *Ap.J. (Lett.)* in which they analyze the prompt emission from gamma-ray bursts in terms of photoionization emission from relativistically moving, dense plasma blobs. They argue that time-resolved spectral analysis early in the GRB is very constraining of the plasma environment and its ultimate origin. They also argue that the line emission seen by GINGA is most naturally interpreted not in terms of cyclotron line emission but in terms of the emission from a complex plasma heated to high temperature and relativistically transformed by bulk motions.

Jimenez-Garate and Hailey are working with Lawrence Livermore National Laboratory to develop improved models for modeling the X-ray spectra of low-mass X-ray binaries and Seyfert galaxies. Hailey, Craig and Hong are collaborating with University of Sheffield in England on an experiment to evaluate use of novel liquid scintillators either as direct dark matter detectors or as highly efficient vetos for next generation dark matter experiments. Josi Gelfand, Craig and Hailey continue a large scale search of the *ROSAT* data base in an attempt to identify possible neutron star candidates for further observation.

Peterson, Rasmussen, and Kahn have measured the scattering and efficiency of the reflection gratings planned for the Constellation-X Mission at the Nevis Longbeam Facility. Preliminary results have suggested a higher first-order efficiency and less scattering compared to the reflection gratings used on XMM mission. Much of the recent attention at the Nevis facility has been devoted to upgrading the detector array at the facility to include a CCD detector.

Peterson, Kahn, Rasmussen, and Jernigan (Berkeley) have been developing advanced Monte Carlo methods for use in X-ray astrophysical data analysis. Specifically, we have been developing techniques that model the expected response of the XMM RGS instrument and produce a simulated data set. This can be compared with the positions and pulse heights of the photons measured with XMM CCD arrays using multivariate nonparametric distribution tests that we have developed. This method of data analysis promises a number of advantages over existing approaches to X-ray spectral analysis which use response matrices. Our method allows for spectral and spatial models of the astrophysical source to be parameterized simultaneously and iteratively modified. The approach also deals particularly well with the complicated instrument response that is found in grating-type spectrometers.

Peterson and Kahn have been working on modeling a pos-

sible design for an X-ray interferometer. The design uses three transmission gratings that interfere X-rays to produce an image of astrophysical sources with microarcsecond angular resolution. From a scalar diffraction theory calculation, we find that the design could have high effective area and angular resolution, but a narrow bandpass. Work is continuing to consider more complicated designs that allow for a larger bandpass.

Kahn, Paerels, Rasmussen, Reynolds, Cottam, Spodek, Sako and Peterson have spent the past year in final preparation for the launch of XMM in December of 1999. We have completed all physical modelling of the Reflection Grating Array (RGA). In order to model the resolution of the instrument we have built a raytrace program based on all known instrumental effects. Including a model of the telescope with the model of the RGA we can predict the Reflection Grating Spectrometer (RGS) instrument profile. These predictions were compared to the calibration data taken at the Panter facility in Munich. Over the instruments range of wavelength, incident angle and spectral order the predicted profiles match the data profiles to within the measurement uncertainties. We have also completed the physical model of the grating efficiency which is used in the effective area calculations. The model is based on a numerical calculation of the full solution to Maxwell's equations subject to the boundary conditions of the grating profile. This is then augmented using scalar theory to account for both a coherent and incoherent redistribution of light. This model successfully reproduces the calibration data of reflectivity as a function of wavelength, incident angle and order with an error of $\sim 5\%$ in first order and $\sim 10\%$ for second order across the instrument band. By including this model of grating reflectivity in the effective area calculation we are able to reproduce the calibration data taken at the Panter facility for the entire RGS effective area to within the same errors. These two instrument models have been incorporated into SCISIM, ESA's official simulation tool, and into the response matrix programs in ESA's Science Analysis System (SAS).

The Science Analysis System is the combined responsibility of the Science Operations Center (SOC) and the Science Survey Consortium (SSC), and consists of both interactive and non-interactive, or "pipeline" software. We have taken on an advisory role working with the SOC in the overall design of the RGS pipeline, the descriptions of specific algorithms, and the implementation and coding of several tasks. We have written a response matrix generator based on our efforts to characterize the RGS instrument. This is an end-to-end description of the spectrometer which includes the results of the psf and efficiency modelling as well as models of the telescope psf and the CCD response. The SAS team has adopted this generator to replace the SCISIM based response in the interactive analysis.

We have programmed observations for the in-flight Calibration (CAL), Performance Verification (PV), and Guaranteed Time (GT) periods. We have built spectral models for each of these sources and simulated the observations in order to check for the optimal exposure times and target phases, to test the feasibility of our scientific objectives and to quantify the expected uncertainty in the spectral diagnostics. During

the first few months we will be doing in-flight calibration to determine the correct wavelength scale and to verify the psf and effective area of the RGS. We are primarily responsible for the wavelength calibration and will be participating in both the psf and effective area verification. For the wavelength scale and psf verification we have scheduled observations of hot stars with strong lines and low continuum emission. The bulk of the calibration will be performed on Capella with additional observations of HR1099, λ And, YY Men, AB Dor, and α Cen. PSR0540-69, with its featureless, stable emission is being used for the primary calibration of the effective area with additional observations of Mkn421, and 3C273. In order to establish the short wavelength area, which is the least well understood, we will perform additional observations of the highly cutoff source GX13+1. We are currently in the process of using these simulations to quantify the expected uncertainty in the derived calibration. The PV period will follow the CAL period and will be used to verify the scientific capabilities of the RGS. Although we will participate on all RGS PV observation, we are primarily responsible for three targets. We will observe the supernova remnant N132D in order to verify the ability of the RGS to do spectroscopy of extended sources. To verify the RGS ability to resolve the spectral signatures of bulk motion we will observe the prototypical wind source ζ Pup and SS433 with its precessing relativistic jets. We are leading the observations for targets in each category of the RGS GT program. We are working on the hot star system ι Ori, and the cool star system σ Gem. We are responsible for five of the brightest and most compact supernova remnants in the Magellanic Clouds. We will observe the two canonical Seyfert II galaxies, Mkn 3 and the Circinus Galaxy, and the bright BL Lac Mkn 501. We are responsible for a wide range of binary systems which include the wind sources Vela X-1 and Cen X-3, the CV source EX Hya, bright LMXB Her X-1 and the previously mentioned SS433 where we will use extensive orbital and precessional phase sampling to constrain the geometry.

Savin and his collaborators P. H. Janzen, L. D. Gardner, D. B. Reisenfeld, and J. L. Kohl (Center for Astrophysics) and K. Bartschat (Drake University) have presented experimental absolute rate coefficients for electron impact excitation of C^{3+} ($2s^2S_{1/2} \rightarrow 2p^2P_{1/2,3/2}$) near threshold. They have also carried out new R matrix calculations with pseudostates (RMPS) calculations for this transition near threshold. Comparison of the RMPS results to those of simpler close-coupling calculations indicates the importance of accounting for target continuum effects. The experimental results are in excellent agreement with the RMPS calculations. Agreement with the RMPS results is better for other published fluorescence technique measurements than for published electron-energy-loss measurements.

Savin and his collaborators D. B. Reisenfeld, L. D. Gardner, P. H. Janzen, and J. L. Kohl (Center for Astrophysics) have measured the absolute cross section for electron-impact excitation (EIE) of Si^{2+} ($3s^21S \rightarrow 3s3p^1P$) from energies below threshold to 11 eV above. A beam modulation technique with inclined electron and ion beams was used. Radiation at 120.7 nm from the excited ion was detected using an

absolutely calibrated optical system. The fractional population of the Si^{2+} ($3s3p^3P$) metastable state in the incident ion beam was determined to be $0.210 \pm 0.018(1.65\sigma)$. The data have been corrected for contributions to the signal from radiative decay following excitation from the metastable state to $3s3p^1P$ and $3p^3P$, and excitation from the ground state to levels above the $3s3p^1P$ level. The experimental 0.56 ± 0.08 -eV energy spread allowed us to resolve complex structure throughout the studied energy range. At the reported $\pm 14\%$ total experimental uncertainty level (1.65σ), the measured structure and absolute scale of the cross section are in good agreement with 12-state close-coupling R -matrix theory.

Savin and his collaborators M. H. Chen and K. J. Reed (Lawrence Livermore National Laboratory) and D. S. Guo (Southern University) have calculated the total dielectronic recombination (DR) coefficients for the $^2P_{1/2}$ and $^2P_{3/2}$ states for B-like Fe^{21+} ions at electron temperatures $0.1 \leq T \leq 10000$ eV. The calculations are carried out using the multiconfiguration Dirac-Fock method in intermediate coupling with configuration interaction. We find that accurate Coster-Kronig energies are critical for a successful determination of low temperature DR coefficients. We also find that the DR involving fine-structure excitations can be as important as the $2s - 2p$ excitation channels in the low temperature regime for some ions. These low temperature DR rates are important for photoionized gases.

Savin, Gu, and Kahn and their collaborators P. Beiersdorfer, B. Beck G. V. Brown, D. A. Liedahl, and J. Scofield (Lawrence Livermore National Laboratory) have used the Lawrence-Livermore electron beam ion trap (LLNL-EBIT) to produce a quasi-Maxwellian plasma. They do this by sweeping the energy of the nearly monoenergetic beam so the time spent at any energy is proportional to the Maxwell-Boltzmann probability at that energy. To verify the accuracy of the quasi-Maxwellian, they have measured line emission due to dielectronic recombination (DR) and electron impact excitation (EIE) of Mg^{10+} and Ne^{8+} , for a range of simulated temperatures. The ratio of DR to EIE lines in helium-like ions is a well understood temperature diagnostic. The spectroscopically inferred temperatures are in excellent agreement with the simulated temperatures. The LLNL-EBIT offers a number of advantages over standard plasma sources for studying Maxwellian plasmas. EBIT is essentially driven by a Maxwellian electron distribution at a single temperature T_e ; a wide range of T_e can be simulated; density effects are generally unimportant; the plasma is optically thin; and T_e is essentially constant along the line of sight. Another advantage is the ability to create ions of a given charge state and then study them in a Maxwellian plasma under non-equilibrium conditions.

Savin and Kahn and their collaborators J. Linkemann, A. A. Saghiri, M. Schmitt, M. Grieser, R. Repnow, D. Schwalm, and A. Wolf (Max-Planck-Institute for Nuclear Physics), T. Bartsch, C. Brandau, A. Hoffknecht, A. Müller, and S. Schippers (University of Giessen), N. R. Badnell (University of Strathclyde) and M. H. Chen (Lawrence Livermore National Laboratory) have carried out new dielectronic recombination (DR) measurements for modeling pho-

toionized gases. In such gases with cosmic abundances, DR proceeds primarily via $nlj \rightarrow nl'j'$ core excitations ($\Delta n = 0$ DR). We have measured the resonance strengths and energies for Fe XVIII to Fe XVII and Fe XIX to Fe XVIII $\Delta n = 0$ DR. Using our measurements, we have calculated the Fe XVIII and Fe XIX $\Delta n = 0$ DR rate coefficients. Significant discrepancies exist between our inferred rates and those of published calculations. These calculations overestimate the DR rates by factors of ~ 2 or underestimate it by factors of ~ 2 to orders of magnitude, but none are in good agreement with our results. Almost all published DR rates for modeling cosmic plasmas are computed using the same theoretical techniques as the above-mentioned calculations. Hence, our measurements call into question all theoretical $\Delta n = 0$ DR rates used for ionization balance calculations of cosmic plasmas. At temperatures where the Fe XVIII and Fe XIX fractional abundances are predicted to peak in photoionized gases of cosmic abundances, the theoretical rates underestimate the Fe XVIII DR rate by a factor of ~ 2 and overestimate the Fe XIX DR rate by a factor of ~ 1.6 . We have carried out new multiconfiguration Dirac-Fock and multiconfiguration Breit-Pauli calculations which agree with our measured resonance strengths and rate coefficients to within typically better than $\leq 30\%$. We provide a fit to our inferred rate coefficients for use in plasma modeling. Using our DR measurements, we infer a factor of ~ 2 error in the Fe XX through Fe XXIV $\Delta n = 0$ DR rates. We investigate the effects of this estimated error for the well-known thermal instability of photoionized gas. We find that errors in these rates cannot remove the instability, but they do dramatically affect the range in parameter space over which it forms.

Using published measurements of dielectronic recombination (DR) resonance strengths and energies for C V to C IV and O VIII to O VII, Savin has calculated the DR rate coefficient for these ions. The derived rates are in good agreement with multiconfiguration, intermediate-coupling and multiconfiguration, fully-relativistic calculations as well as with most LS coupling calculations. The results are not in agreement with the recommended DR rates commonly used for modeling cosmic plasmas. He has used theoretical radiative recombination (RR) rates in conjunction with our derived DR rates to produce a total recombination rate for comparison with unified RR+DR calculations in LS coupling. The results are not in agreement with undamped, unified calculations for C V but are in reasonable agreement with damped, unified calculations for O VIII. For C V, the Burgess general formula (GF) yields a rate which is in very poor agreement with Savin's derived rate. The Burgess & Tworkowski modification of the GF yields a rate which is also in poor agreement. The Merts et al. modification of the GF yields a rate which is in fair agreement. For O VIII the GF yields a rate which is in fair agreement with our derived rate. The Burgess & Tworkowski modification of the GF yields a rate which is in good agreement. And the Merts *et al.* modification yields a rate which is in very poor agreement. These results suggest that for $\Delta n = 1$ DR it is not possible to know *a priori* which formula will yield a rate closer to the true DR rate. Savin describes the technique used to obtain DR rate coefficients from laboratory measurements

of DR resonance strengths and energies. For use in plasma modeling, we also present easy-to-use fitting formulae for the experimentally derived DR rates.

Savin and Gu and their collaborators E. Träbert (Ruhr University), P. Beiersdorfer, G. V. Brown, and S. B. Utter (Lawrence Livermore National Laboratory) and A. J. Smith (Morehouse College) have measured the lifetime of the $1s2s^3S_1$ level of the He-like Ne^{8+} ion using the Lawrence-Livermore Electron Beam Ion Trap. The lifetime is important for electron density plasma diagnostics which use the line produced by the radiative decay of the forbidden $1s2s^3S_1 - 1s^2^1S_0$ transition in heliumlike oxygen. The measured lifetime distinguishes among theoretical values as agreement is obtained only with those calculations that employ “exact” non-relativistic or relativistic wavefunctions.

Gu, Kahn, and Savin and their collaborators P. Beiersdorfer, G. V. Brown, D. A. Liedahl, and K. J. Reed (Lawrence Livermore National Laboratory) and C. P. Bhalla and S. R. Grabbe (Kansas State University) have used the Lawrence-Livermore electron beam ion trap to measure the relative cross sections for Fe XXIV line emission at electron energies between 0.7 and 3.0 keV. The measurements include line formation by direct electron impact excitation (DE), radiative cascades, resonant excitation (RE), and dielectronic recombination (DR) satellites with captured electrons in $n \geq 5$ levels. Good agreement with R -matrix and distorted wave is found. In collisionally ionized plasmas, at temperatures where the ion abundance peaks ($kT_e \sim 1.7$ keV), the RE contributions are found to be $\leq 10\%$. While good agreement with state-of-the-art atomic physics calculations is found, there is less good agreement with existing spectral synthesis codes in common astrophysical use. For the Fe XXIV $3p_{3/2} \rightarrow 2s_{1/2}$, $3p_{1/2} \rightarrow 2s_{1/2}$, and $3d_{5/2} \rightarrow 2p_{3/2}$ transitions, the synthesis code MEKAL underestimates the emissivity in coronal equilibrium by $\sim 20\%$ at temperatures near where the ion abundance peaks. In situations where the ionization balance is not solely determined by the electron temperature, RE and DR satellites may contribute a considerable fraction of the line emission.

Kahn and his collaborators P. Beiersdorfer, J.K. Lepson, G. V. Brown, S. B. Utter, D. A. Liedahl, and C. W. Mauche (Lawrence Livermore National Laboratory) have measured the line emission of Fe VII-Fe X ions in the extreme-ultraviolet region below 140 Å in controlled laboratory experiments under conditions representative of the stellar coronae. The observations have been compared with predictions from standard spectral models using the CHIANTI and MEKAL atomic databases. They have found that the atomic databases miss most of the line flux in this region. While some of the missing lines form isolated features, most add up to form a quasi continuum in the 60-120 Å region. This incompleteness can explain the poor fit when applying global-fitting techniques to spectra from cool stars measured by the *Extreme-Ultraviolet Explorer* satellite, the origin of which has been a source of controversy since the original observations were made.

Kahn and his collaborators J. J. Drake (Center for Astrophysics), D. A. Swartz (Marshall Space Flight Center), and P. Beiersdorfer, and G. V. Brown (Lawrence Livermore Na-

tional Laboratory) have re-examined the emission line feature at 17.62 Å in solar X-ray spectra. Using a Monte Carlo technique, they compute a realistic upper limit to the observed Fe $L\alpha$ photospheric fluorescent line strength caused by irradiation from an overlying corona. These calculations demonstrate that the photospheric $L\alpha$ characteristic line is much too weak to account for the observed 17.62 Å line flux. Instead, we identify this line with the configuration interaction $2s^22p^43p^2P_{3/2} - 2s2p^6^2S_{1/2}$ transition in Fe XVIII seen in Electron Beam Ion Trap Spectra and predicted in earlier theoretical work on the Fe XVIII X-ray spectrum. This line should be easily resolved and detected in stellar coronae by the spectrographs on the upcoming CXO and XMM missions.

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