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[S0002-7537(98)03401-5]

1. THEORY

1.1 Theoretical Cosmology Group

The Theoretical Cosmology group, which consists of faculty members J. Frieman, E.W. Kolb, A. Olinto, D.N. Schramm, and M.S. Turner, pursues a vigorous program of research on topics ranging from red shift $Z = 10^{32}$ to $Z = 0$. Emphasis is placed on the application of modern particle theory to cosmology, especially the earliest history of the Universe. Members of the group are also involved in the Sloan Digital Sky Survey project. Current topics of research include inflationary cosmology, the origin of density perturbations, topological defects (monopoles, strings, walls, textures), cosmological phase transitions (electroweak, QCD, GUT), baryogenesis, particle dark matter and its detection, primordial nucleosynthesis, the evolution of structure in the Universe, the origin of CBR anisotropies, gravitational waves, and the origin of highest energy cosmic rays. The group helped to pioneer the use of the Universe as a ‘‘heavenly laboratory’’ to probe fundamental physics in regimes not accessible in terrestrial laboratories and has used such arguments to constrain the properties of axions, neutrinos, neutralinos, and magnetic monopoles. The Theoretical Cosmology group works closely with the Theoretical Astrophysics group at Fermilab which is led by Frieman and whose faculty members are S. Dodelson, J. Frieman, E.W. Kolb, A. Stebbins, and M.S. Turner.

PUBLICATIONS

M. Abney, E. Copeland, E.W. Kolb, A.R. Liddle, and J.E. Lidsey. ‘‘The Inflation Potential from Present Day Observations,’’ *Nucl. Phys. B* **43**, 118 (1995).

B. Cheng, A.V. Olinto, D.N. Schramm and J.W. Truran. ‘‘Constraints on the Strength of Primordial Magnetic Fields from BBN Revisited,’’ *Phys. Rev. D*, submitted (1996).

C.J. Copi and D.N. Schramm. ‘‘The Nuclear Impact on Cosmology: The $H_0 - \Omega$ Diagram,’’ *Comments on Nuclear and Particle Physics* **22**, 1-18 (1995).

C.J. Copi, D.N. Schramm and M.S. Turner. ‘‘Assessing Big-Bang Nucleosynthesis,’’ *Phys. Rev. Lett.*, **75**, No. 22, 3981-3984 (1995).

C.J. Copi, D.N. Schramm and M. Turner. ‘‘Big Bang Nucleosynthesis and a New Approach to Galactic Chemical Evolution,’’ *ApJ*, **455**, L95-98 (1995).

C.J. Copi, D.N. Schramm and M. Turner. ‘‘The Big Bang Nucleosynthesis Limit to the Number of Neutrino Species,’’ *Phys. Rev. Lett.*, submitted (1996).

D.S.P. Dearborn and D.N. Schramm. ‘‘Is There a Pop II Analogy to the F Star Li-Dip,’’ *PNAS*, in press (1996).

S. Dodelson, E. Gates and M.S. Turner, ‘‘Cold Dark Matter Models,’’ *Science*, submitted (1996).

S. Dodelson, E. Gates and A. Stebbins, ‘‘Cold + Hot Dark Matter and the Cosmic Microwave Background,’’ *ApJ*, in press (1996).

J. Ellis, B.D. Fields and D.N. Schramm. ‘‘Geological Isotope Anomalies as Signatures of Nearby Supernovae,’’ *ApJ*, in press **470** (October 20, 1996).

G. R. Farrar and E.W. Kolb. ‘‘Light Photinos as Dark Matter,’’ *Phys. Rev. D*, **53**, 2990 (1996).

R. Ferlet and M. Lemoine ‘‘Interstellar Abundances of the Light Elements,’’ in Proc. of 6th Annual October Conference in Maryland, eds. G. Sonneborn and S. Holt, PASP, in press (1996).

R. Ferlet, M. Lemoine and A. Vidal-Madjar. ‘‘Deuterium in the Local Interstellar Medium,’’ in *Science with the Hubble Space Telescope - II*, eds. P. Benvenutti, F. Machetto and E. Schreir, STScI, in press (1996).

R. Ferlet, M. Lemoine and A. Vidal-Madjar. ‘‘Deuterium in the Local Interstellar Medium,’’ in Proc. of IInd Rencontres du Vietnam: The Sun and Beyond, eds. D. Kunth and J. Tran Thanh Van, in press (1996).

B.D. Fields, G.J. Mathews and D.N. Schramm. ‘‘Halo White Dwarfs and the Hot Intergalactic Medium,’’ *ApJ Lett.*, submitted (1996).

E. Gates, G. Gyuk and M.S. Turner, ‘‘Gravitational Microlensing and the Galactic Halo,’’ *Phys. Rev. D* **53**, 4138 (1996).

E. Gates, G. Gyuk and M.S. Turner, ‘‘The Local Halo Density,’’ *ApJ Lett.* **449**, L123 (1995).

E. Gates, G. Gyuk and M.S. Turner, ‘‘Microlensing and Halo Cold Dark Matter,’’ *Phys. Rev. Lett.* **74**, 3724 (1995).

E. Gates, L. Krauss, and M. White, ‘‘Treating Solar Model Uncertainties: A Consistent Statistical Analysis of Solar Neutrino Models and Data,’’ *Phys. Rev. D* **51**, 2631 (1995).

E. Gates, G. Gyuk and M.S. Turner, Gravitational Microlensing and Halo Dark Matter,’’ in the proceedings of the UCLA Dark Matter 96 Conference, Santa Monica, CA, in press (1996).

D. Grass and E.W. Kolb. ‘‘Cosmological Bounds to the Magnetic Moment of Heavy Tau Neutrinos,’’ *Phys. Rev. D*, in press (1996).

A.F. Heckler and E.W. Kolb. ‘‘Searching for Stellar Mass Black Holes in the Solar Neighborhood,’’ *ApJ Lett.*, submitted (1996).

W. Hu, D. Spergel, M. White. ‘‘Distinguishing Causal Seeds from Inflation,’’ *Phys. Rev. D.*, submitted (1996); astro-ph/9605193

W. Hu, M. White. ‘‘Acoustic Signatures in the Cosmic Microwave Background,’’ *ApJ*, in press (1996); astro-ph/9602019

W. Hu, M. White. ‘‘A New Test of Inflation,’’ submitted to Phys. Rev. Lett., astro-ph/9602020

W. Hu, M. White. ‘‘Measuring the Curvature of the Universe,’’ in *Microwave Background Anisotropies*, Proceedings of the XXXIth Rencontres de Moriond, in press (1996)

A.H. Jaffe and M.S. Turner. ‘‘F=Gamma Rays and the Decay of Neutrinos from SN 1987A,’’ *Phys. Rev. D*, in press (1996).

M. Janssen, D. Scott, M. White, M. Seiffert, C. Lawrence, K. Gorski, M. Dragovan, T. Gaier, K. Ganga, S. Gulkis, A. Lange, S. Levin, P. Lubin, P. Meinhold, A. Readhead, P. Richards, J. Ruhl. ‘‘Direct Imaging of the CMB from Space,’’ *ApJ*, submitted (1996); astro-ph/9602009.

E.W. Kolb. ‘‘Big Bang,’’ in the *Macmillan Encyclopedia of Physics*, (Macmillan, New York, 1996).

E.W. Kolb. *Blind Watchers of the Sky*, (Helix Books, 1996).

E.W. Kolb. ‘‘Deducing the Value of the Cosmological Constant During Inflation from Present-Day Observations,’’ in *The Cosmological Constant and the Evolution of the Universe,* K. Sato, T. Suginohara, and N. Sugiyama, eds., (Universal Academy Press, Tokyo), p. 169.

E.W. Kolb. ‘‘From the Big Bang to Now, and the Journey Back,’’ *Proceedings of the 1995 Valencia Meeting on Dark Matter and the Universe,* J. W. Valle, ed., in press (1996).

E.W. Kolb. ‘‘The Inflation Potential from Present Day Observations,’’ in *Trends in Astrophysics*, L. Bergstrom, P. Carlson, P. O. Huth, and H. Snellman, eds., (North-Holland, 1995), p. 118.

E.W. Kolb. ‘‘Introduction to Cosmology,’’ in *Proceedings of the 1995 Trieste Astroparticle School*, R. Carrigan and G. Giocamelli, eds., in press (1996)

E.W. Kolb. ‘‘Lectures on Inflation,’’ in the *Proceedings of the 1995 Varenna Summer School*, in press (1996).

E.W. Kolb. ‘‘Light Photinos as Dark Matter,’’ in *Sources and Detection of Dark Matter,* D. Cline, ed. (1996).

E.W. Kolb. ‘‘Light Photinos as Dark Matter, or SUSY off the Well Groomed Trails,’’ in *Rencontres de Physique de la Vallee d'Aosta*, G. Bellettini and M. Greco, eds. (Frascati Physics Series, 1996).

E.W. Kolb. ‘‘Light photinos and supersymmetric dark matter,’’ in *Proceedings of the 1995 Coral Gables Conference*, B. Kursunoglu and S. Perlmutter, eds., in press (1996).

E.W. Kolb. ‘‘New Guises for Old Dark-Matter Suspects,’’ in *Relativistic Astrophysics*, B. Jones, ed. (Cambridge University Press, 1996).

E.W. Kolb. ‘‘New Ideas for Dark Matter,’’ in *Proceedings of the 7th International Meeting on Neutrino Telescopes,* M. Baldo-Ceolin, ed., in press (1996).

E.W. Kolb. ‘‘The Potential of Potential Reconstruction,’’ in *Birth of the Universe and Fundamental Physics, F. Occhionero*, ed., (Springer, Berlin, 1995) p. 35-44.

E.W. Kolb. ‘‘Potential Reconstruction,’’ in *Frontier Objects in Astrophysics and Particle Physics*, F. Giovannelli and G. Mannocchi, eds., (Editrice Compositori, Bologna, 1995) p. 3.

E.W. Kolb. ‘‘Reconstructing the Inflation Potential,’’ in *Proceedings of the 1994 Coral Gables Conference*, B. Kursunoglu and S. Perlmutter, eds., in press (1996).

E.W. Kolb. ‘‘Snowmass 1994,’’ in *CERN Courier* (1995).

E.W. Kolb, A. F. Heckler and M. Gleiser. ‘‘Modeling Thermal Fluctuations: Phase Mixing and Percolation,’’ *Phys. Rev. Lett.*, submitted (1995).

E.W. Kolb, A. D. Linde and A. Riotto. ‘‘GUT Baryogenesis after Preheating,’’ *Phys. Rev. Lett.*, submitted (1996).

E.W. Kolb, R.N. Mohapatra and V.L. Teplitz. ‘‘New Supernova Constraints on Sterile Neutrino Production,’’ *Phys. Rev. D*, submitted (1996).

E.W. Kolb. and R. D. Peccei, eds. *Particle and Nuclear Astrophysics and Cosmology in the Next Millennium* (World-Scientific Publishing Company, 1995).

E.W. Kolb and A. Riotto. ‘‘Eternal Annihilations of Light Photinos,’’ *Phys. Rev. D*, submitted (1996).

E.W. Kolb and A. Riotto. ‘‘Preheating and Symmetry Restoration in Collisions of Vacuum Bubbles,’’ *Phys. Rev. D*, submitted (1996).

E.W. Kolb and I.I. Tkachev. ‘‘Femtolensing and Picolensing by Axion Miniclusters,’’ *ApJ Letters*, **460**, L25 (1996).

A. Kosowsky and M.S. Turner. ‘‘CBR Anisotropy and the Running of the Scalar Spectral Index,’’ *Phys. Rev. D*, **52**, R1739 (1995).

L. Krauss and M.S. Turner. ‘‘The Cosmological Constant is Back,’’ *General Relativity and Gravitation*, **27**, 1137 (1995).

A.H. Jaffe and M.S. Turner. ‘‘Gamma Rays and the Decay of Neutrinos from SN 1987A,’’ *Phys. Rev. D*, in press (1996).

S. Lee, A. Olinto, and G. Sigl. ‘‘Extragalactic Magnetic Field and the Highest Energy Cosmic Rays,’’ *ApJ Lett.* **455**, L21-L24 (1995).

M. Lemoine, D.N. Schramm, J.W. Truran and C.J. Copi. ‘‘On the Significance of Pop II ^{6}Li Abundances,’’ *ApJ*, submitted (1996).

M. Lemoine, E. Vangioni-Flam and M. Casse. ‘‘Galactic Cosmic Rays and the Evolution of the Light Elements,’’ *ApJ*, submitted (1996).

A.R. Liddle, D.H. Lyth, P.T.P. Viana and M. White. ‘‘Cold Dark Matter Models with a Cosmological Constant,’’ *MNRAS*, in press; astro-ph/9512102 (1996).

J. E. Lidsey, A. R. Liddle, E.W. Kolb, E. J. Copeland, T. Barreir, and M. Abney. ‘‘Reconstructing the Inflation Potential—an Overview,’’ *Rev. Mod. Phys.*, submitted (1995).

K.A. Olive, R.T. Rood., D.N. Schramm, J.W. Truran and E. Vangioni- Flam. ‘‘What's the Problem with ^{3}He?’’ *ApJ*, **444**, 680- 685 (1995).

K.A. Olive and D.N. Schramm, ‘‘Big Bang Nucleosynthesis,’’ in L. Montadet *et al.*, *Phys. Rev. D* **50**, 1173 (1994) and 1995 off-year particle update for the 1996 edition available on the PDG WWW pages (URL: http://pdg.lbl.gov/).

G. Raffelt, D. Seckel, and G. Sigl. ‘‘Supernova Neutrino Scattering Rates Reduced by Nucleon Spin Fluctuations: The Perturbative Limit,’’ preprintFERMI-LAB-Pub-96/058-A, astro-ph/9603044, *Phys. Rev. D*, in press (1996).

D.N. Schramm, C. Copi and X. Shi. ‘‘Cosmological Implications of Nuclear Physics,’’ in Proc. of Summer School on Cosmology, Australian National University, January 16-February 3, 1995, Canberra, Australia, in press (Singapore: World Scientific, 1995).

D.N. Schramm, ''An Astrophysics Overview,'' in Proc. of IInd Rencontres du Vietnam: 'The Sun and Beyond,' Dec. 1995, Ho Chi Minh City, Vietnam, in press (1996).

D.N. Schramm. ''Dark Matter,'' in *Rencontres de Physique de la Vallée d'Aoste: Results and Perspective in Particle Physics* (Proc. of La Thuile '95, March 1995), ed. M. Greco (INFN-Laboratori Nazionali di Frascati, Frascati Physics Series, Vol. II, 1995) pp. 97-121.

D.N. Schramm. ''The Particle-Cosmology Connection: Dark Matter and Large Scale Structure,'' in Proc. of the International Symposium on Particle Theory and Phenomenology, May 1995, Ames, Iowa, ed. A. Sommerer (Singapore: World Scientific, 1995), in press.

D.N. Schramm. ''Primordial Nucleosynthesis,'' in Proc. of the 6th Annual Astrophysics Conference in Maryland: Cosmic Abundances, October 1995, Greenbelt, MD, eds. S.S. Holt and G. Sonneborn, in press (Provo, Utah: Astronomical Society of the Pacific, 1996).

D.N. Schramm. ''The Solar Neutrino Situation: A Theorist's Perspective,'' in *Weak and Electromagnetic Interactions in Nuclei* (Proc. of the IV International Symposium, Osaka, Japan, June 1995). eds. H. Ejiri, T. Koshimoto, and T. Sato (Singapore: World Scientific, 1995) pp. 125-134.

D.N. Schramm and M.S. Turner. ''Deuteronomy and Numbers,'' *Nature*, **381**, 193 (1996).

S.T. Scully, M. Cassé, K.A. Olive, D.N. Schramm, J. Truran and E. Vangioni-Flam. ''The Local Abundance of ^{3}He: A Confrontation Between Theory and Observation,'' *ApJ*, **462**, 960-968 (1996).

G. Sigl, ''Weak Interactions in Supernova Cores and Saturation of Nucleon Spin Fluctuations,'' *Phys. Rev. Lett.* **76** (1996) 2625-2628.

G. Sigl, ''Topological Defects and Ultrahigh Energy Cosmic and Gamma Rays,'' invited talk at the Heidelberg TeV Gamma Ray Workshop, Heidelberg, 3-7 Oct. 1994, *Space Science Reviews* **75** (1996) 375-385.

G. Sigl, K. Jedamzik, D.N. Schramm, and V.S. Berezinsky. ''He Photodisintegration and Nucleosynthesis: Implications for Topological Defects, High Energy Cosmic Rays and Massive Black Holes,'' *Phys. Rev. D*, **52**, 6682-6693 (1995).

G. Sigl and S. Lee. ''Possible Astrophysical Sources for the Highest Energy Cosmic Rays,'' OG Sessions, Vol. 2, pp. 356-359; S. Lee and G. Sigl. ''Propagation of Ultra High Energy Photons through the Intergalactic Medium,'' OG Sessions, Vol. 1, pp. 536-539, in Proceedings of the *24th International Cosmic Ray Conference*, Rome, 28 Aug.-8 Sept. 1995 (Istituto Nazionale Fisica Nucleare, Rome, 1995).

G. Sigl, S. Lee, and P. Coppi. ''The Universal γ-Ray Flux, Grand Unified Theories, and Extragalactic Magnetic Field,'' preprint FERMILAB-Pub-96/087-A, astro-ph/9604093, submitted to *Phys. Rev. Lett.* (1996).

G. Sigl, S. Lee, D. N. Schramm, and P. Bhattacharjee. ''A Gap in the Highest Energy Cosmic Ray Spectrum As A Signature of Unification Scale Physics,'' *Science* **270**, 1977-1980 (1995).

G. Sigl, D.N. Schramm, S. Lee, P. Coppi and C.T. Hill. ''Implications of a Possible Clustering of Highest Energy Cosmic Rays,'' *ApJ Lett.*, submitted (1996).

R.W. Strickland and D.N. Schramm, ''Concordance of X-Ray Cluster Data with BBN in Mixed Dark Matter Models,'' *ApJ*, in press (1995).

M.S. Turner, J.W. Truran, D.N. Schramm and C.J. Copi. ''Cosmological Implications of the First Measurement of the Local ISM Abundance of ^{3}He,'' *ApJ Lett.*, in press **466**, L59 (August 1, 1996).

M.S. Turner and Y. Wang. ''A Fast and Accurate Algorithm for Computing Tensor CBR Anisotropy, *Phys. Rev. D*, **53**, 5727 (1996).

M. Turner and M. White. ''Dependence of Inflationary Reconstruction upon Cosmological Parameters,'' *Phys. Rev. D*, in press; astro-ph/9512155.

M.S. Turner and M. White. ''Reconstruction of the Inflationary Potential with a Cosmological Constant,'' *Phys. Rev. D*, *53*, 6822 (1996).

M. White. ''Cosmic Confusion and Structure Formation,'' *Phys. Rev. D* **53**, 3011 (1996).

M. White and W. Hu. ''Testing Inflation with Small Scale CMB Anisotropies,'' in *Microwave Background Anisotropies*. Proceedings of the XXXIth Rencontres de Moriond, in press (1996).

M. White, D. Scott. ''The Impact of the Microwave Background on Large Scale Structure,'' *Comments on Astrophysics*, in press (1996); astro-ph/9601170.

M. White, P.T.P. Viana, A.R. Liddle, D. Scott. ''Cold Dark Matter Models with High Baryon Content,'' *MNRAS*, submitted; astro-ph/9605057.

1.2 Arieh Königl

During the past year, Königl and his collaborators have continued to explore the important, and varied, effects of magnetic fields on the accretion and outflow phenomena observed in young stellar objects (YSOs) and active galactic nuclei (AGNs). In the context of YSOs, further work has been carried out on the applicability of magnetized disk models, in which centrifugally driven winds transport the excess angular momentum of the accreted matter, to the various physical regimes of realistic circumstellar disks around solar-mass stars. In particular, the existence and properties of viable solutions in the high density inner disk regions, where either ambipolar diffusion or Ohmic resistivity dominate the magnetic field diffusivity, have been investigated in collaboration with M. Wardle (U. Sydney). In addition, numerical simulations of such disks have been undertaken in collaboration with M.-M. Mac Low (MPI Heidelberg). Work has also started (in collaboration with graduate student J. Landry) on the interpretation of the strong YSO accretion and outflow events known as FU Orionis outbursts in terms of a magnetized, wind-driving disk that undergoes a thermal ionization instability. A necessary ingredient of the wind-driving disk scenario is the presence of ordered, open magnetic field lines in the disk. The possibility that the field is a relic of the rotational collapse of the molecular cloud core from which the disk had formed is being studied by means of a full-fledged numerical simulation by postdoctoral research associate G. Ciolek. The alternative possibility that the field was carried in during the subsequent evolution of the disk by means of field-mediated accretion is being considered by postdoctoral research associate J. Contopoulos, who has formulated it as a time-dependent boundary-value problem. In other work that built on his earlier results on the effects of dust and magnetic field in collapsing clouds, Ciolek demonstrated that ambipolar diffusion can significantly reduce the abundance of small grains in protostellar cores. He has also started to investigate the effect that this, in turn, would have on the evolution of the abundances of ionized species in collapsing cores, with early results pointing to significant deviations from previous *non*evolutionary chemical equilibrium models. He has also been involved in the study of the propagation of hydromagnetic waves and instabilities in weakly ionized, self-gravitating molecular clouds in collaboration with T. Mouschovias & S. Morton (U. Illinois). Contopoulos, too, has engaged in other collaborative research: with D. Kazanas (GSFC) & C. Fendt (Lund Obs.) on the interpretation of γ-ray emission from pulsars in terms of curvature radiation in a hydromagnetic electron–positron pulsar wind, and with K. Tsinganos & G. Surlantzis (U. Crete), C. Sauty (Paris Obs.), and E. Trussoni (Torino Obs.) on critical points and separatrix characteristics in solar and astrophysical MHD flows. Motivated by growing evidence that some of the distinguishing observational properties of YSOs arise from the interaction of a strong stellar magnetic field with a circumstellar disk, graduate student S. Martin studied the thermal structure of magnetic accretion funnels that form when the field disrupts the disk before it reaches the stellar surface and then channels the accreted matter to high stellar latitudes, where it is decelerated in high-temperature accretion shocks. Some of his main findings were that the principal heat source is adiabatic compression of the convergent flow and that the Ca II and Mg II ions act as a thermostat that regulates the gas temperature as it approaches the stellar surface. Preliminary results have indicated that this model might successfully account for the Brγ and CO bandhead emission from low-mass (and possibly also intermediate-mass) YSOs. Following the first EUV spectroscopic observations of a BL Lac object (PKS 2155-304), which were conducted by Königl and collaborators last year, another successful detection of a BL Lac object (Mrk 421) was obtained with the *EUVE* satellite. Postdoctoral research associate J. Kartje and Königl, working in collaboration with C.-Y. Hwang & S. Bowyer (UC Berkeley), have demonstrated that the EUV spectra of the two objects are very similar when considered in their respective rest frames, and that both can be interpreted in terms of Doppler-smeared absorption lines originating in high-velocity, QSO-type clouds that are ionized by the beamed continuum of the associated relativistic jet. Kartje, Contopoulos, & Königl are developing a model of diamagnetic clouds that interact with both a disk-driven hydromagnetic wind and a strong nuclear radiation source and are applying it to the interpretation of high-velocity clouds in both BL Lac objects and QSOs.

PUBLICATIONS

Königl, A., Kartje, J. F., Bowyer, S., Kahn, S. M., and Hwang, C.-Y. (1995). ‘‘The Extreme Ultraviolet Spectrum of the BL Lacertae Object PKS 2155-304,’’ *Ap. J.*, **446**, 598

Königl, A. (1995). ‘‘Active Galactic Nuclei in the Extreme Ultraviolet,’’ *Highlights of Astronomy*, **10**, 517

Königl, A. (1996). ‘‘Active Galactic Nuclei in the Extreme Ultraviolet,’’ in *Astrophysics in the Extreme Ultraviolet*, ed. S. Bowyer and R. F. Malina (Cambridge: Cambridge Univ. Press), 27

Königl, A. (1995). ‘‘Disk-Driven Hydromagnetic Winds in Young Stellar Objects,’’ *Rev.MexAA (Conf. Ser.)*, **1**, 275

Königl, A., and Wardle, M. (1996). ‘‘A Comment on the Stability of Magnetic Wind-Driving Accretion Discs,’’ *M. N. R. A. S.*, **279**, L61

Kartje, J. F. (1995). ‘‘Models of the Optical/Ultraviolet Continuum Polarization in Active Galactic Nuclei: Implications for Unification Schemes,’’ *Ap. J.*, **452**, 565

Kartje, J. F., Königl, A., Hwang, C.-Y., and Bowyer, S. (1997). ‘‘The Extreme Ultraviolet Spectrum of the BL Lacertae Object Mrk 421,’’ *Ap. J.*, **474**, 000

Buckley, J. H., *et al.* (1996). ‘‘Gamma-Ray Variability of the BL Lacertae Object Markarian 421,’’ *Ap. J.*, **472**, L000

Tsinganos, K., Sauty, C., Surlantzis, G., Trussoni, E., and Contopoulos, I. (1997), ‘‘Critical Points and Separatrix Characteristics in Solar and Astrophysical MHD Flows,’’ *M.N.R.A.S.*, in press

Martin, S. C. (1996). ‘‘The Thermal Structure of Magnetic Accretion Funnels in Young Stellar Objects,’’ *Ap. J.*, **470**, 537

Martin, S.C., (1996). ‘‘Thermal Radio Emission from Disk-Driven Centrifugal Winds,’’ *Ap. J.*, **473**, 000

Ciolek, G. E. (1996). ‘‘Magnetic Fields, Interstellar Dust, UV Radiation, and Star Formation,’’ in *The Role of Dust in the Formation of Stars*, ESO Workshop Series, ed. H. U. Käufl and R. Siebenmorgan (Berlin: Springer), in press

Ciolek, G. E., & Mouschovias, T. Ch. (1996). ‘‘Effect of Ambipolar Diffusion on Dust-to-Gas Ratio in Protostellar Cores,’’ *Ap. J.*, **468**, 749

Orton, G. O., *et al.* (1995). ‘‘Collision of Comet Shoemaker-Levy 9 with Jupiter Observed by the NASA Infrared Telescope Facility,’’ *Science*, **267**, 1277

Chu, Y.-H., Chang, H.-W., Su, Y.-L., and Mac Low, M.-M. (1995). ‘‘X-Rays from Superbubbles in the Large Magellanic Cloud. III. X-ray Dim Superbubbles,’’ *Ap. J.*, **450**, 157

Zahnle, K., Mac Low, M.-M., Lodders, K., and Fegley, B., Jr. (1995). ‘‘Sulfur Chemistry in the Wake of Comet Shoemaker-Levy 9,’’ *Geophys. Res. Lett.*, **22**, 1593

Zahnle, K., and Mac Low, M.-M. (1995). ‘‘A Simple Model for the Light Curve Generated by a Shoemaker-Levy 9 Impact,’’ *J. Geophys. Res., Planets*, **100**, 16885

García-Segura, G., and Mac Low, M.-M. (1995). ‘‘Wolf-Rayet Bubbles. I. Analytic Solutions,’’ *Ap. J.*, **455**, 145

García-Segura, G., and Mac Low, M.-M. (1995). ‘‘Wolf-Rayet Bubbles. II. Gas Dynamical Simulations,’’ *Ap. J.*, **455**, 160

García-Segura, G., Mac Low, M.-M., and Langer, N. (1996). ‘‘The Dynamical Evolution of Circumstellar Gas Around Massive Stars. I. The Impact of the Time Sequence OStar $\rightarrow$ LBV $\rightarrow$ WR Star,’’ *A & A*, **305**, 229

García-Segura, G., Mac Low, M.-M., and Langer, N. (1996). ''The Hydrodynamical Evolution of Circumstellar Gas Around Massive Stars. II. The Impact of the Time Sequence OStar → RSG → WR Star,'' *A & A*, **305**, 229

1.3 Don Q. Lamb

The focus of my research is the physics of matter and radiation under extreme conditions. Compact objects such as white dwarfs, neutron stars, and black holes provide an astrophysical laboratory for such studies. Their high internal densities enable non-ideal Coulomb solids, heavy nuclei, nuclear matter, and even quark matter to be probed. Hot dense matter is also crucial to an understanding of supernovae. The large gravitational potentials and the strong magnetic fields at the surfaces of these objects produce phenomena ranging from radio pulsars to active galactic nuclei. These phenomena can be used to test our understanding of nuclear reactions, hydrodynamics and shocks, and radiation transfer in magnetoactive and relativistic plasmas in new regimes, as well as to determine the properties, such as mass, radius, and magnetic field, of the compact objects themselves. My current research activities include projects in the following areas: properties of relativistic pair plasmas and hot dense matter; structure and evolution of degenerate dwarfs and neutron stars; supernovae, pulsars; X-ray emission from degenerate dwarfs and neutron stars; X-ray and gamma-ray bursts; and active galactic nuclei.

1.4 Robert Rosner

R. Rosner and collaborators conduct both theoretical and observational research in solar and stellar astrophysics, more general plasma astrophysics, and fluid dynamics. In the area of (astrophysical) fluid dynamics and magnetohydrodynamics, we have continued our studies of thermal instabilities in galaxy cluster halos and cooling flows; thus, former graduate student L. Tao has continued collaborating in a study of the effects of turbulence in magnetic field line stretching, and whence in modifying electron thermal conduction, in cluster halos, showing that very large suppression of conduction by such magnetic fields is highly unlikely. In collaboration with S.K. Chakrabarti, S. Vainshtein and R. Rosner have considered the possible role of massive black holes in generating ''primordial'' galactic magnetic fields. Substantial attention has been focused on the evolution of magnetic fields in the more general context of turbulent fluid flows; thus, F. Cattaneo, E. Kim, L. Tao and collaborators (including D. Hughes and M. Proctor) have looked at the processes leading to ''saturation'' in magnetic dynamo flows; and former graduate student E. Kim is pursuing numerical and analytical studies of turbulent magnetic diffusion in partially ionized fluids. We have also carried out combined theoretical and modeling studies of the evolution of solar surface magnetic fields; thus, L. Tao, Y. Du, R. Rosner, and F. Cattaneo have studied the emergence of fractal structures in surface distributions of magnetic fields immersed in turbulent conducting fluids. We have also re-focused our attention on the problem of mixing at shear boundaries; for example, A. Malagoli has continued an ambitious effort to construct a multi-dimensional Godunov scheme for magnetohydrodynamic simulations, and recent simulations involving this code include a study of Kelvin-Helmholz instability for a magnetized shear layer (with G. Bodo/Torino and R. Rosner). Finally, in collaboration with J. Toomre and N. Brummell (U. Colorado/ Boulder), F. Cattaneo has reviewed the subject of solar convection. Our interests in the propagation and reflection of mhd waves in atmospheres has substantially increased over the past year, as the relevance of these processes for the dynamics of the outer atmospheres of active giant stars (including hybrid stars) has become clearer; the observational work has been largely focused on ROSAT observations (V. Kashyap and R. Rosner in collaboration with F.R. Harnden [NASA], Jr., A. Maggio, G. Micela, and S. Sciortino [Osservatorio di Palermo]), while the model building has been carried out by R. Rosner in collaboration with Z.E. Musielak [UA Huntsville], F. Cattaneo [Chicago], R.L. Moore and S.T. Suess [NASA / Marshall]. Detailed calculations of wave propagation are now a major focus: Y.Q. Lou and R. Rosner have carried out analytical studies of Alfven wave propagation and reflection in stellar atmospheres; and in collaboration with S. Orlando and G. Peres (both Osservatorio di Palermo) and Z. Musielak (UA Huntsville), we have begun a program of numerical simulations of these processes. Z. Musielak [UA Huntsville] has also collaborated with us in studying the generation of such waves in stellar surface layers (with R. Rosner [Chicago], P. Gail, and P. Ulmschneider [Univ. of Heidelberg]). In the more general area of stellar astrophysics, V. Kashyap and R. Rosner, together with D. Schramm and J. Truran, have considered the effects of MACHOs on the diffuse soft X-ray background; and have used ROSAT observations to study the X-ray properties of coeval stars in the Pleiades open cluster. An outgrowth of this latter type of work has been the development of methods for characterizing low-resolution X-ray spectra (led by A. Collura [Palermo], in collaboration with G. Micela and S. Sciortino [Palermo], F.R. Harnden [NASA], and R. Rosner [Chicago]). Finally, in the more general cosmological context, W. Klemperer [Harvard], D. Schramm, X. Luo, and R. Rosner have studied the possible role of coherently stimulated recombination in generating structure at the time of recombination.

PUBLICATIONS

Kashyap, V., Rosner, R., Schramm, D., & Truran, J. 1994, ApJ (Letters), 431, L87-L90

Chakrabarti, S.K., Rosner, R., & Vainshtein, S.I. 1994, Nature, 368, 434-6

Lou, Y.Q., & Rosner, R. 1994, ApJ, 424, 429-35

Kashyap, V., Rosner, R., Harnden, Jr., F.R., Maggio, A., Micela, G., & Sciortino, S. 1994, ApJ, 431, 402-15

Rosner, R., Musielak, Z.E., Cattaneo, F., Moore, R.L., & Suess, S.T. 1995, ApJ (Letters), 442, L25-8

Klemperer, W., Luo, X., Rosner, R., & Schramm, D.N. 1995, Proc. Natl. Acad. Sci. USA, 92, 6166-70

Schramm, D.N., Rosner, R., Luo, X.,& Klemperer, W. 1995, Proc. Natl. Acad. Sci. USA, 92, 6171-4

Tao, L., Du, Y., Rosner, R., & Cattaneo, F. 1995, ApJ, 443, 434-43

Collura, A., Micela, G., Sciortino, S., Harnden, F.R., Jr., & Rosner, R. 1995, ApJ, 446, 108-14
Berger, M.A., & Rosner, R. 1995, Geophys. Astrophys. Fluid Dyn., in press
Musielak, Z.E., Rosner, R., Gail, P., & Ulmschneider, P. 1995, ApJ, in press
Micela, G., Sciortino, S., Kashyap, V., Harnden, F.R., Jr., & Rosner, R. 1995, ApJ Suppl., in press
Cattaneo, F., Kim, E., Tao, L., & Proctor, M.R.E. 1995, PRL, in press
Toomre, J., Cattaneo, F., & Brummell, N.H. 1995, Science, in press
Cattaneo, F., Hughes, D.W., & Kim, E. 1995, Nature, submitted
Malagoli, A., Bodo, G., & Rosner, R. 1995, ApJ, in press

1.5 James W. Truran

Truran, Ami Glasner, and Eli Livne have completed a preliminary investigation of the influence of convection on thermonuclear ignition of hydrogen burning in accreted shells on white dwarfs, using two dimensional simulations. The earliest stages of the runaway were calculated using a 1D hydrodynamic code developed by Glasner and Truran (1996). When the temperature at the base of the accreted envelope reached 10^8 K and the total rate of nuclear energy generation was approximately $10^5 L_\odot$ (e.g the runaway was fully developed), the 1D flow was mapped onto a 2D grid and the simulation continued in two dimensions, using the code VULCAN developed by Livne (1993; see also Glasner and Livne 1995). The 2D grid consisted of 90 radial zones and 220 equal lateral zones, occupying an angle of 0.1 'pi' radians, and included both the entire accreted hydrogen layer and the upper 15 zones of the underlying carbon-oxygen core. At the onset of the stage of evolution studied with the 2D code, the envelope was already convectively unstable. Within a very short time (approximately 10 seconds), the numerical noise acted to seed an intense convective flow in the envelope, without the introduction of any artificial perturbations. The initial convective cells were found to be almost circular and of a size comparable to the pressure scale height ($\sim 10^7$ cm), while the convective velocities were close to the values predicted by the mixing length theory - several times 10^6 cm/sec. After a relatively short transition period of order 40 seconds, the flow reached a quasi-steady state, where convection was fully developed. The buildup of convective cells at the base of the envelope induced shear flow at the core-envelope interface, which is Kelvin-Helmholtz unstable, and mixing between the outer layers of the core and the burning zone ensued. By the end of their simulation, covering approximately 240 seconds of the evolution of the runaway, the hydrogen envelope had been 'enriched' to about 30 percent by mass in carbon and oxygen from the underlying core. Such a level of enrichment is entirely consistent with observations of the compositions of the ejected shells of classical novae (Livio and Truran 1995) and with our theoretical understanding of the thermonuclear outbursts of novae. The outward mixing of the short lived positron-unstable isotopes O^{14}, O^{15}, F^{17}, and F^{18} also served to redistribute the nuclear energy output from the nuclear burning shell (charged particle reactions can only occur in the hotter regions near the base of the envelope) and thereby to moderate the temperature gradient across the envelope. Such studies are critical to our ultimate understanding of the nature of the outbursts of classical novae - including our understanding of the early evolution of the visual light curves, which is immediately relevant to the use of bright novae as distance indicators to nearby galaxies.

1.6 Peter O. Vandervoort

Vandervoort continues to investigate the oscillations and the stability of stellar systems. The formulation of the work is based on a Lagrangian representation of small perturbations. The present effort concentrates on the development of numerical N-body codes for the representation of Lagrangian perturbations in stellar systems. These codes do not perform N-body calculations in the conventional sense. They make use of numerical N-body methods in order to provide a numerical realization of the analytic theory of small perturbations in a linear approximation. Codes for the representation of radial oscillations of a spherical stellar system have been written and thoroughly tested and studied. For the sake of economy and speed, an explicit calculation of the Eulerian perturbation of the acceleration of each body is replaced with a representation as a superposition of orthonormal polynomials. With as few as 100 to 1000 bodies, the code accurately reproduces analytic results for the fundamental mode of radial oscillation in a homogeneous sphere of stars and in a polytropic sphere of index n = 1. As represented in the N-body calculation, these systems suffer parametric resonance and chaotic behavior; these attributes of the N-body calculation can be controlled with a suitable choice of initial conditions and with the inclusion of a sufficiently large (but not unreasonable) number of bodies in the calculation. Future work will deal with higher modes of radial oscillation and with nonradial modes in spheres and with perturbations in more general three-dimensional configurations.

2. HISTORY

2.1 Noel M. Swerdlow

From late April until the beginning of August of 1995 I was a Visiting Fellow at All Souls College, Oxford. My principal research there was working on a book on astronomy in the Renaissance concentrating on the principal figures of Regiomontanus, Copernicus, Tycho, Kepler, and Galileo (although what I have written on Galileo is so extensive that it will probably be a separate book). During the period in Oxford I was both writing and doing research in the Bodleian. Also while at All Souls, I gave two lectures at the college, and at Cambridge, London, and the Warburg Institute on various subjects from Babylonian astronomy to Newton. My book on Babylonian planetary theory has been accepted for publication by Princeton University Press. A detailed description of its contents was given in my last report, and I am currently revising and expanding the original manuscript. I have written the introduction, mostly on the history of scholarship on Babylonian astronomy and celestial divination, for a collection of papers I am editing, called

Ancient Astronomy and Celestial Divination, presented at a conference held at the Dibner Institute for the History of Science and Technology at MIT in May of 1994. I have also contributed a shorter version of the study of Babylonian planetary theory to the collection, specifically, on the derivation of parameters from records of the dates of phenomena, which is the central subject of the book. Based upon my longer manuscript on Galileo, I have written a fairly long general survey called ''Galileo's Contribution to Astronomy and Conflict with the Church'' that will appear in a volume called *The Cambridge Companion to Galileo* (unless they tell me it is too long, in which case they can forget it!).

PUBLICATIONS

''Astronomy in the Renaissance.'' *Astronomy before the Telescope.* British Museum Press.

''Galileo's Contribution to Astronomy and Conflict with the Church.'' *The Cambridge Companion to Galileo.* Cambridge University Press.

''The Derivation of the Parameters of Babylonian Planetary Theory with Time as the Principal Independent Variable.''

''Introduction to Ancient Astronomy and Celestial Divination.'' Both of these are in *Ancient Astronomy and Celestial Divination.* Dibner Institute Studies in the History of Science and Technology (published by The University of Chicago Press). The volume is currently being reviewed by the Press.

The Babylonian Theory of the Planets. Princeton University Press. Accepted and currently being revised and expanded.

3. EXPERIMENTATION

3.1 John E. Carlstrom

John Carlstrom has joined the faculty and continues his research with Caltech graduate students Laura Grego and Nils Halverson, and with research associate William Holzapfel. Following is a list of current projects. (1) Mapping the Sunyaev-Zeldovich effect in distant galaxy clusters. Centimeter wavelength maps of the Sunyaev-Zeldovich effect in distant galaxy clusters have been made by the Owens Valley Millimeter Array and the BIMA array at Hat Creek, retrofitted with cm-wavelength receivers. The summer of '96 is the third season of observing. Over a dozen clusters have been mapped to date, some with a signal-to-noise $>$ 20. (2) The Very Compact Array (VCA). The VCA is in the design phase. It will consist of an interferometric array of 13 cm-wavelength feedhorns, which will map anisotropy in the Cosmic Microwave Background Radiation on angular scales from 20' to 1 degree. The experiment will make observations from the South Pole. (3) Submillimeter Interferometry. The Caltech Submillimeter Observatory (CSO) and the James Clerk Maxwell Telescope (JCMT), both submillimeter wavelength telescopes atop Mauna Kea, have been successfully linked together to form a 2 dish interferometer with arcsecond resolution. At this resolution it is possible to resolve protoplanetary disks, yielding clues to star formation. (4) Polarimetry interferometric imaging of protostars and star forming regions.

3.2 Roger Hildebrand

Hildebrand's students, Darren Dowell and David Schleuning, have completed their PhD. theses within the last year. Dowell is now a postdoc at Caltech; Schleuning is a postdoc at The University of Chicago. Both are continuing to collaborate with the Hildebrand group. Giles Novak and Jessie Dotson (Northwestern) are also regular collaborators. A new student, John Vaillancourt, has joined the group. The current research activity is directed to 350 μmm observations at the Caltech Submillimeter Observatory with the University of Chicago polarimeter, Hertz. These observations have yielded over 500 measurements within the last year. A second instrument, SPARO, being constructed by the Northwestern group, will provide complementary observations at 800 μmm. The 350 μmm results combined with those previously obtained at 60 μmm, and 100 μmm with the U of Chicago polarimeter, Stokes, on the Kuiper Airborne Observatory provide the first opportunity to examine far-infrared/submillimeter polarization spectra. The unusual nature of the polarization spectrum for Sgr B2 has indicated polarization by selective absorption: the only known example in the far-infrared (Dowell 1997; PhD thesis). By mapping the polarization vectors at scores of points in individual objects it has been possible to infer the configuration of the magnetic fields in many objects. Field maps of the core of the Orion Nebula at 100 μmm, 350 μmm and 450 μmm have given evidence of magnetically regulated collapse in a region of high mass star formation (Schleuning 1998; PhD thesis). Early results on a core in DR 21 appear to provide a second example of magnetically regulated collapse. Questions under investigation are a) Why is the polarization spectrum near intensity peaks different from that in cloud envelopes (after removing optical depth effects)? b) Can the spectrum be fitted assuming a single species of aligned grains (doubtful)? c) Must the standard model for interstellar dust be modified to fit the far-infrared/submillimeter spectrum? Work is continuing on instrumental improvements for Hertz and on design of a future polarimeter for SOFIA.

PUBLICATIONS

Hildebrand, R. H. & Dragovan, M. The Shapes and Alignment Properties of Interstellar Dust Grains, ApJ. 450, 663,1995

Schleuning, D. A., Dowell, C. D., & Platt, S. R. Array Polarimetry of the Orion Nebula from the Caltech Submillimeter Observatory, in Polarimetry of the Interstellar Medium, eds. W. G. Roberge & D. C. B. Whittet, ASP Conference Series San Francisco. p.285- 289,1996.

Hildebrand, R. H. Problems in Far-Infrared Polarimetry, in Polarimetry of the Interstellar Medium, eds. W. G. Roberge & D. C. B. Whittet, ASP Conference Series, vol. 97. San Francisco. p 254 - 268, 1996

Dotson, J. L. Polarization of the Far-Infrared Emission of M17. ApJ 470: 566-576, 1996

Schleuning, D. A., Dowell, C. D., Hildebrand, R. H. & Platt, S. R. Hertz, A Submillimeter Polarimeter. PASP 109:307-318, 1997

Dowell, C. D. Far-Infrared Polarization by Absorption in the Molecular Cloud Sagittarius B2. ApJ. 487, 237, 1997

Novak, G., Dotson, J. L., Dowell, C. D., Goldsmith, P. F., Hildebrand, R. H., Platt, S. R., & Schleuning, D. A. Polarization of the l = 115 μmm Radiation from Sagittarius B2. ApJ. 487, 320, 1997

Schleuning, D. A. Far-Infrared and Submillimeter Polarization of OMC-1 - Evidence for Magnetically Regulated Star Formation. ApJ, In press, 1998

3.3 Edward Kibblewhite

The work of the Kibblewhite research group focuses on developing new techniques to achieve diffraction-limited imaging in fully-filled apertures and distributed arrays of telescopes. The full resolution of ground-based telescopes will be achieved at near infrared wavelengths using a laser beam to generate an artificial star in the sodium layer of the earth's atmosphere. This star will enable the instantaneous wavefront of the atmosphere to be measured and these data used to correct for the atmospheric distortion using adaptive optics and post processing of the images. Faint objects can be studied with a resolution of 0.05 arcsecond using the ARC telescope. The system will allow fundamentally new observations of objects from planets to distant galaxies. Baselines of hundreds of meters are needed to study the environment and surfaces of stars or the core of active nuclei. Distributed arrays of telescopes can provide such resolutions using synthesis techniques developed in radio astronomy. Such arrays pose formidable technical and system engineering problems requiring the development of stable telescopes, precision delay lines and correlators stable to nanometers over the short observation periods. A 5- or 6-telescope array is being planned using 0.6-meter telescopes operating in the near infrared. The Kibblewhite group currently consists of graduate students Mark Chun, Fang Shi, and Michael Smutko, research associate Walter Wild, and computer programmer Vijuna Scor. James Larkin recently relocated to UCLA. Kibblewhite and Wild are involved in studying the effects of severe turbulence and scintillation on imaging and optical wavefronts. This work has application to low elevation astronomical adaptive optics systems, deep space optical communications, horizontal imaging, and the Airborne Laser program. They have developed a 5.5 kilometer long horizontal path facility at Yerkes Observatory using the 41 inch reflector and the 4 kHz Wavefront Control Experiment (WCE) adaptive optics system in a coude laboratory; a laser at the distant target range serves as a beacon for the WCE wavefront sensor. A variety of targets configurations can be used to study issues such as the isoplanatic angle as a function of the wavefront estimator and atmospheric conditions. A visiting student, E. O. Le Bigot, from the ENS in France, played a key role in developing algorithms for the detection of discontinuities (branch points) in the wavefront and their reconstruction for use in an adaptive optics system; we are analyzing Hartmann-Shack data to verify the existence of these branch points. The adaptive optics coude laboratory is also used for testing other novel instruments, such as the Stellar Products low order adaptive system, the AO-5, which will eventually be situated at the Meyer-Womble Observatory on Mount Evans in Colorado. Wild also has been developing the matrices used to control the 3.5m adaptive optics system at the USAF Starfire Optical Range, and at other sites across the country. Entirely new classes of control matrices have been developed and tested using the WCE, which should find benefit at various astronomical adaptive optics systems to optimize performance based on site and hardware characteristics. Wild has developed a new flat field reconstruction procedure that is independent of the external illumination source. The approach may have benefits to the HST, planetary landers, and for deep field photometry over large area arrays in the infrared. Wild is also involved in setting up a Near Earth Object asteroid search program using the Yerkes Observatory 24 inch reflector and a team of local amateur astronomers. They will also work to refurbish a Meinel spectrograph for the 41 inch telescope which will be used for asteroid classification, cataclysmic variable, and supernovae observations. It is also planned to utilize algorithms developed by Wild to use photometric lightcurves to estimate pole orientations of asteroids; this effort is being led by a team at the U. Wisconsin Eau Claire. Wild and Rosner are involved in another program using the Yerkes 41 inch as part of an international collaboration headed by Alessandro Cacciani (U. Rome), with team members W. Rodgers (Eddy Company) and Neil Murphy (JPL), to search for p-mode oscillations in Jupiter using a magneto-optical filter system. Presently the equipment is being tested and optimized to be ready for coordinated observations during the 1998 opposition season. Two similar devices will be constructed for future use on the Yerkes 40 inch refractor for simultaneous solar Dopplergram and magnetogram measurements. Wild and Evans are also using the 41 inch to do follow up observations of suspected optical counterparts to gamma ray bursters. A new SITe CCD camera delivered to Yerkes will increase capability significantly for detecting faint (>25th V mag) objects in several hours of integration.

3.4 Stephan S. Meyer

Measurements of the properties of the Cosmic Microwave Background Radiation (CMBR) are aimed at bettering our understanding of the nature and evolution of the early universe. Our group was part of the COBE satellite mission which first detected large angular scale (>10 degrees) anisotropy in the CMBR with the DMR experiment and made a precision measurement of the spectrum from 30 to 400 GHz with the FIRAS experiment. At the same time, we completed and flew a balloon-borne instrument, the Far InfraRed Survey (FIRS) which then confirmed the COBE anisotropy detection with a cross-correlation of the two data sets. We are currently completing observations at angular scales of 0.5 degrees with the Medium Scale Anisotropy Measurement (MSAM). Observations at these smaller scales are sensitive to the dynamics and evolution of matter at the time of early structure formation. A new gondola, TopHat is being currently being constructed. It will fly from Antarctica on a Long Duration Balloon (LDB) with a 1 meter telescope placed on top of the balloon where the observing environment is near ideal. A key element of this research is the development and characteriza- tionof a new kind of bolometer system. Using a bolometric element with finite resistance metal structures as part of a traditional interference filter, a device with controlled reflection, transmission, and absorption properties may be built – thus the name Frequency Selective Bolometer (FSB). The advantages of the device over traditional bolometric systems is improved sensitivity and extremely small size in a multi-spectral radiometer useful in the wavelength range from 50 microns to 2 mm. We are part of a new satellite project, Microwave Anisotropy Probe (MAP) which will observe the entire sky with 0.3 degree resolution. It is planned to launch in 2000 and will operate in the Sun-Earth L2 libration point in a near optimal environment.

PUBLICATIONS

Inman, C. A., *et al.* ''Statistical Comparison of the MSAM-92 and MSAM-94 Results,'' Ap.J. (Submitted January 1996).

Fixsen, D. J., *et al.* ''A Balloon-Borne Millimeter-Wave Telescope for Cosmic Microwave Background Anisotropy Measurements,'' Accepted, ApJ (Submitted December 1995)

Cheng, E. S., *et al.* ''MSAM 1-94: Repeated Measurement of Medium- Scale Anisotropy in the Cosmic Microwave Background Radiation,'' ApJ 456:L71 (1996)

Kowitt, M. S., *et al.* ''Frequency Selective Bolometers,'' Accepted Applied Optics (Submitted December 1995)

Bennett, C. L., *et al.* ''Cosmic Temperature Fluctuations from Two Years of COBE DMR Observations,'' ApJ 436:423 (1994)

3.5 Richard H. Miller

Dynamics of Galaxies is a beautiful problem in Computational Physics. Beautiful objects (galaxies and star clusters) are studied by means of a beautiful formalism (Hamiltonian mechanics). We conduct numerical experiments on self-consistent, self-gravitating systems by means of fully three-dimensional $n-$body computer programs. Relaxation effects are suppressed by using 100,000 to a million particles. The programs have proven extremely versatile. They serve as a laboratory for studies on the dynamics of galaxies, clusters of galaxies, star clusters, and so on. Important discoveries have come from this work. These include, among others (1) that galaxies oscillate in normal modes with surprisingly large amplitudes, (2) that the gravitational $n-$body problem is chaotic, (3) that barlike forms are dynamically preferred for rapidly rotating self-consistent stellar systems while the traditional axisymmetric disk-like form is dynamically unstable, (4) that the nucleus of a galaxy orbits around the galaxy's mass centroid, which can cause the nucleus to appear slightly off-center or to have a velocity that differs from the rest of the galaxy by tens of km/sec, and (5) that strong contractions that take place as galaxies collide are normal modes of oscillation. Recent work includes a dynamical study of the double nucleus discovered in the Andromeda nebula (M31) by the Hubble Space Telescope, and a study whether certain globular clusters can withstand the tidal stresses they endure as the orbit within the Galaxy. This last allows us to elucidate the physical processes at work that cause a cluster to be disrupted.

4. OBSERVATION

4.1 Kyle M. Cudworth

Cudworth has continued his proper motion and photometric studies of star clusters using plates from the Yerkes 40-inch refractor and a variety of other telescopes, scanned on the PDS microdensitometer at MADRAF (located at the University of Wisconsin). While the primary long-term emphasis of this program is globular clusters, some work on open clusters has continued, as well as studies of dwarf spheroidal galaxies. The Yerkes telescope began its second century of activity with Cudworth's observations on 21 May 1997, exactly 100 years after first light. Cudworth prepared a review of star cluster proper motion work which was presented at the Minnesota conference on Proper Motions and Galactic Astronomy. Cudworth is continuing his collaboration with S. Majewski (Virginia) and others in a program to obtain proper motions for distant globulars and dwarf spheroidals. In addition to deriving membership for stars in these systems (many of which are very sparse) we are deriving tangential velocities using galaxies and QSO's to set the zero-point of the proper motions, thus allowing derivation of the orbits of the distant satellites and better constraining estimates of the mass of the Milky Way. A paper discussing the sparse globular Pal 5 is nearly complete, while some progress has been made on the studies of Pal 13, Pal 15, and Arp 2. Cudworth has thoroughly investigated astrometric membership of stars in the Ursa Minor dSph galaxy as an extension to the thesis work by Schweitzer (former student at Wisconsin) on the proper motion of the UMi system. A journal paper describing the entire project, co-authored with Schweitzer and Majewski, has been submitted. In addition to membership probabilities for stars over a large area of UMi, they have derived an absolute proper motion of the system with unprecedented precision, yielding a total Galactocentric space velocity of 209 +/- 20 km/s. Ursa Minor is moving along the Magellanic Stream in the same sense as the Large Magellanic Cloud. R. Rees spent much of the year at Yerkes Observatory before moving to a postdoc position at Minnesota. Much of his time was devoted to his program of deriving distances to globular clusters by comparing proper motion and radial velocity dispersions. In particular, he has worked with Cudworth on improvements to the proper motions in NGC 6397 derived here a few years ago (but not yet published). As further contribution to the distance-derivation program, Cudworth used the latest improvements in the Yerkes cluster proper motion code to re-reduce the M2 proper motions published a decade ago. In further work on relatively nearby globulars Cudworth extended his plate measurements for proper motions in 47 Tuc to and beyond the nominal tidal radius in an effort to identify very outlying cluster members. C. Anderson (Wisconsin) also participated in the PDS scanning for this project. K and H. Cudworth organized and ran the Yerkes Space Explorer program funded by NASA IDEA grants. This is an educational outreach directed toward middle-school students in communities near Yerkes Observatory. Students constructed 4-inch telescopes from kits and participated in astrophotography and CCD imaging projects as well as other hands-on activities. J. Briggs, R. Evans, and R. Rees provided valuable assistance. Presentations regarding this program were made to two science teacher organizations in Wisconsin during this report year.

PUBLICATIONS

Cudworth, K. M. ''Proper Motion Studies of Star Clusters and Related Objects,'' in ASP Conf. Ser. 127 in Proper Motions and Galactic Astronomy, ed. R. M. Humphreys, p. 91, 1997

Schweitzer, A. E., Cudworth, K. M., & Majewski, S. R. ''The Proper Motion of the Dwarf Spheroidal Galaxy Ursa Minor,'' in ASP Conf. Ser. 127 in Proper Motions and Galactic Astronomy, ed. R. M. Humphreys, p. 103, 1997

Rees, R. F., Jr. ''Astrometric Distances to Globular Clusters: New Results,'' in ASP Conf. Ser. No. 92, in The Formation of the Galactic Halo . . . Inside and Out, ed. H. Morrison and A. Sarajedeni, p. 289, 1996

Rees, R. F., Jr. ''Astrometric Distances to Globular Clusters,'' in ASP Conf. Ser. No. 127, in Proper Motions and Galactic Astronomy, ed. R. M. Humphreys, p. 109, 1997

DeGioia-Eastwood, K., Throop, H., Walker, G. & Cudworth, K. ''The Star Formation History of Tr 14 and Tr 16,'' BAAS, 29, 1997

Schweitzer, A. E., Cudworth, K. M., & Majewski, S. R. ''The Absolute Proper Motion and a Membership Survey of the Ursa Minor Dwarf Spheroidal Galaxy,'' (submitted to AJ)

4.2 Douglas K. Duncan

Duncan continues to serve as Education Coordinator for the American Astronomical Society. Recent research includes a detailed investigation of beryllium and boron abundances in stars of different metallicities, aimed to test the mechanisms responsible for the formation of these two light elements and their evolution along the entire galactic history (with F. Primas, L.M. Rebull, A.M. Boesgaard, C.P. Deliyannis, L.M. Hobbs, J.R. King, S. Ryan, and J. Thorburn; published in Ap. J. 488, 338). Work on the determination of the B11/B10 isotopic ratio (with L.M. Rebull, S. Johansson, J. Thorburn, B. Fields) has produced a rough limit on the ratio in the metal-poor star HD 76932, with evidence for a possible blending feature in the spectrum (presented at the Cool Stars 10 Conference). Former postdoctoral associate F. Primas accepted a position at ESO. She and Duncan have determined from HST observations that several stars identified as Be weak in Primas' thesis are also deficient in boron. Thesis student L.M. Rebull continues work on the evolution of rotation rates and Li abundances of very young late-type stars in clusters. Duncan has also begun research on the use of peer, small-group instruction in large introductory astronomy classes for non-majors. Initial results seem extremely positive.

4.3 Doyal A. Harper, Jr.

Harper and his research group continue to use Infrared and submillimeter techniques to study processes related to the formation and evolution of stars, planetary systems, and galaxies.

4.4 Lewis M. Hobbs

Since July 1, 1995, and with a variety of colleagues, I have carried out studies (1) of the light elements lithium, beryllium, and boron in the early Galaxy and (2) of the Galactic interstellar medium. These investigations relied primarily upon high-resolution spectra obtained in the ultraviolet, optical, and/or the radio wavelength regions. Some highlights of the work are the following.

4.4.1 Li, Be, and B in the Early Galaxy

With D. Duncan, L. Rebull, F. Primas (all Univ. of Chicago), and others, we carried out a pioneering study of the evolution of the abundance of boron in the early Galaxy. New spectra of eight halo stars with $-3.0 < [Fe/H] < -0.3$ were recorded in the region of the 2497 A lines of B I, using the HST/GHRS. The principal result is that the variation of B/H with Fe/H over this wide range in Fe/H is fit well by a straight line of slope unity. For the same set of ten stars, a similar result is found for Be/H vs. Fe/H, when previously published data for Be are utilized. These results suggest that B and Be are produced by cosmic-ray spallation reactions of energetic C, N, and O nuclei onto protons and alpha particles in the interstellar medium, rather than vice versa, as had previously been thought. With J. Thorburn (Univ. of Chicago), we performed a careful study of the abundances of beryllium in six halo stars with $-2.6 < [Fe/H] < -0.9$. New spectra were obtained at Kitt Peak in the region of the 3130 A lines of Be II, and detailed spectrum syntheses were used in this crowded spectral region to infer the various [Be/H] fractions. The principal results are that a fairly strong, unidentified line blended with the weaker Be II line may spuriously raise the [Be/H] values deduced especially for cooler, more metal-rich stars; that abundances derived only from approximate estimates of the equivalent widths of the Be II lines can be substantially in error; and that the otherwise nearly identical stars HD 94028 and HD194598 show Be abundances which differ by a factor of about 2. With D. Lubowich (Hofstra Univ.) and B. Turner (NRAO), we completed a pioneering search for lithium and boron in the interstellar medium near the Galactic Center (GC). The method adopted was to look for absorption toward the GC in the ground-state hyperfine-structure lines ($F=1$ to 2) of Li I and B I at 804 and 732 Mhz respectively, using the 43m telescope at Green Bank. No absorption was detected above moderately sensitive limits, at either line. The principal conclusions are that the GC has had neither an extended period of AGN activity, nor a very large cosmic-ray flux, nor a large gamma-ray flux, any of which could have produced detectable Li and/or B in the GC, and that the gaseous deuterium previously detected there by a similar method probably originated in the infall of primordial matter.

4.4.2 Interstellar Matter

With D. York, D. Welty, J. Lauroesch (all Univ. of Chicago), and D. Morton (Herzberg Inst. of Astrophysics), we reported the second known detection of the very heavy element lead (Z=82) in the interstellar gas. Very weak absorption was seen at the 1433 A line of Pb II in the spectrum of 1 Sco, using the HST/GHRS. If the theoretical transition probability adopted for this transition is correct, the depletion of lead from the gas is stronger than is expected from the low condensation temperature of lead. Selected additional observations of interstellar lead could illuminate the formation and evolution of interstellar grains. With D. York, D. Welty, J. Trapero, J. Lauroesch (all Univ. of Chicago), L. Spitzer (Princeton U.), and D. Morton (Herzberg Inst. of Astrophysics), we carried out a detailed study of interstellar clouds seen toward 23 Ori and Tau CMa at radial velocities of about -100 km/s, and also of two apparently circumstellar ''clouds'' seen toward Eta Tau at about -149 and -42 km/s. New HST/GHRS observations of numerous UV absorption lines indicated that these clouds in front of 23 Ori and Tau CMa consist of warm, ionized gas which is not yet in a steady-state equilibrium, and which is now cooling after having been previously shocked, presumably in a Type II supernova explosion. An immediate signature of this gas is the very high C II/O I (or Si III/O I) ratio found in it. The apparently circumstellar ''clouds'' seen toward Eta Tau show a remarkably high C II*/C II ratio, perhaps owing to optical pumping of the gas by the star. With D. Welty (Univ. of Chicago) and D. Morton (Herzberg Inst. of Astrophysics), we measured Ca II absorption lines arising in 417 individual interstellar clouds seen toward 44 stars. The new spectra obtained at Kitt Peak and the AAT/UHRF were characterized by high resolution and high S/N ratios. As a group, the Ca II component line widths exceed those of corresponding Na I components, suggesting that Ca II occupies a somewhat larger volume, characterized by a higher temperature and/or turbulent velocity, than Na I does. Ca II absorption can arise in cold, relatively dense gas, where Ca is heavily depleted and Ca II is the dominant ionization state, and also in warmer gas of lower density, where Ca is less depleted and Ca III is the dominant ionization state. With Trapero, M. Sempere (both Univ. of Chicago), and J. Beckman (IAC), we further investigated the properties of a large, massive molecular cloud located only about 120 pc from the Sun, which was previously studied by Trapero. New observations of CO emission from two molecular cores located within the H I cloud were obtained with the 12m telescope at Kitt Peak. These two cloudlets show diameters of about 1 pc, molecular densities of about 100 cm^{-3}, and masses of about 1 solar mass; they are not virialized but probably are confined by turbulent pressure.

PUBLICATIONS

Trapero, J., Welty, D. E., Hobbs, L. M., Lauroesch, J. T., Morton, D. C., Spitzer, L., & York, D. G. 1996. ''High-Velocity Gas in GHRS Spectra of Three OB Stars,'' ApJ, 468, 290

Welty, D. E., Morton, D. C., & Hobbs, L. M. 1996, ''A High-Resolution Survey of Interstellar Ca II Absorption,'' ApJS, 106, 533

D. K. Duncan, F. Primas, L. M. Rebull, A. M. Boesgaard, C. P. Deliyannis, L. M. Hobbs, J. R. King, & S. G. Ryan 1997, '' The Evolution of Galactic Boron and the Production Site of the Light Elements,'' ApJ, 488, 338

D. E. Welty, J. T. Lauroesch, J. C. Blades, L. M. Hobbs, & D. G. York 1997, ''Interstellar Abundances in the Magellanic Clouds. I. GHRS Observations of the SMC Star Sk 108,'' ApJ, 489, 672

L. M. Hobbs & J. A. Thorburn 1997, ''Lithium Isotope Ratios in Halo Stars. II,'' ApJ (12/20/97 issue)

4.5 Stephen M. Kent

Stephen Kent continues as computing coordinator for the Sloan Digital Sky Survey and has overall responsibility for data acquisition and data processing software for that project. He has also taken a more active roll in project management issues on the SDSS, coordinating inter-institutional activities on the telescope construction and working with others on the project to improve the schedule and cost estimates for the project. His research interests are in galactic structure, structure and dynamics of galaxies and galaxy clusters, and large-scale photometric surveys.

4.6 Richard G. Kron

Kron worked to develop the operations plan for the Sloan Digital Sky Survey, which will include observations at Apache Point Observatory and running the data-reduction pipelines at Fermilab. He continues as Head of the Experimental Astrophysics Group at Fermilab. While the Sloan Digital Sky Survey will target galaxies that are typically at redshifts less than 0.2, Kron has maintained programs targeting galaxies at much higher redshifts. The deep redshift survey that Kron, D. Koo (UC Santa Cruz), and their collaborators have been undertaking at Kitt Peak National Observatory for several years was completed, and the paper containing the catalog was accepted for publication. Moreover, Kron continues to be associated with the DEEP project (based at UC Santa Cruz) which is targeting faint galaxies with the Keck 10-m telescope and with the WFPC2 camera on the Hubble Space Telescope. Kron, with graduate students M. Takamiya and B. Holden, have been undertaking observations with the ARC 3.5-m telescope at Apache Point Observatory with the GRIM near-infrared instrument and the Double Imaging Spectrograph. Takamiya's thesis program relates to imaging galaxies with compact structures and strong emission lines in the K band to constrain the star-formation rate at $z \sim 0.4$ for this type of galaxy. Holden, with R. Nichol, is studying samples of distant clusters of galaxies defined by optical and X-ray properties. Holden is also involved in an international collaboration conducting an X-ray-selected survey for clusters of galaxies which will double the current high-redshift sample. This survey uses sophisticated source detection and identification techniques to ensure a high rate of completeness and minimize contamination from other sources of X-ray emission. Takamiya has developed a metric of the fraction of the light in a galaxy image that arises from young stellar populations, specifically the modulation at high spatial frequencies from OB associations. She has tested the metric on a nearby sample with independent estimates of the current star-formation rate, and is working on applying the method to deep HST images.

PUBLICATIONS

A.R. Sandage, R.G. Kron, & M.S. Longair. ''The Deep Universe,'' eds. B. Binggeli and R. Buser, Saas-Fee Advanced Course 23, Lecture Notes 1993, (Springer-Verlag), p 233, 1995

R.G. Kron. ''Digital Optical Sky Surveys,'' PASP 107, 766, 1995

R. Guzman, D.C. Koo, S.M. Faber, G.D. Illingworth, M. Takamiya, R.G. Kron, and M.A. Bershady. ''On the Nature of Faint Compact Narrow Emission-Line Galaxies: The Half-Light Radius - Velocity Width Diagram,'' ApJ 460, L5, 1996

A.J. Connolly, I. Csabai, A.S. Szalay, D.C. Koo, R.G. Kron, and J.A. Munn. ''Slicing Through Multicolor Space: Galaxy Redshifts from Broadband Photometry,'' AJ 110, 2655, 1995

M.T. Ruiz & M.Y. Takamiya. ''Spectroscopic Follow-Up of Large Proper Motion Stars in ESO Areas 207, 439, and 440,'' AJ 109, 2817, 1995

M.Y. Takamiya, & R.G. Kron. ''Structural Parameters of Field Galaxies with HST and ARC 3.5m,'' BAAS Vol 27, No. 4, p. 1361, 1995

4.7 Takeshi Oka

In collaboration with T.R. Geballe of the Joint Astronomy Centre, we have detected interstellar H^{3+} in dense clouds towards the direction of young stellar objects GL2136 and W33A using the CGS4 infrared spectrometer of UKIRT [T.R. Geballe and T. Oka, Nature, 384, 334 (1996)]. This has provided the most direct evidence for the ion-neutral reaction scheme for the chemical evolution of molecular clouds. Subsequent observations conducted under the leadership of graduate student Ben McCall in a sequence of 8 observational sessions encompassing 28 nights, in UKIRT with T.R. Geballe and at KPNO with K. Hinkle, have revealed that H^{3+} is abundant not only in dense clouds but also in diffuse clouds.

4.8 Patrick Palmer

In the past year, I have continued to work in two areas: study of the interstellar medium and study of comets. One large project, a radio continuum and spectroscopic study of the Sagittarius D star- forming region (in collaboration with D. M. Mehringer, W. M. Goss, and D. C. Lis, and Karl M. Menten) was also completed and has been accepted for publication in the Astrophysical Journal Supplement. However, because of the fortuitous appearance of bright comets in the Springs of the last two years, cometary work has dominated my activities.

4.8.1 Comets Hyakutake and Hale – Bopp

Comet Hyakutake made its closest approach to the Earth in March, 1996. It was a ''new comet,'' discovered only about six weeks before closest approach. Although there was little time to plan observations, a number of ''target of opportunity'' observations were arranged with several instruments. Comet Hale-Bopp, in contrast, was discovered more than two years before closest approach, and we had time to plan a large campaign to observe it. Therefore, the first half of 1997 was involved in actually carrying out observations (although some observations began in September, 1996). Analysis of this data is barely underway. Because the cometary community rallied to obtain as much information as possible from these rare events, the collaborations that ensued are too complex to list, but can be seen in the author lists of the resulting papers. Data obtained on Comet Hyakutake came from the Very Large Array (VLA), Very Long Baseline Array (VLBA), the Berkeley - Illinois - Maryland Array (BIMA), and the 43m and 12m telescopes of the National Radio Astronomy Observatory (NRAO). Analysis of the resulting data took place this year. Probably the most interesting result so far was the first clear detection of NH_3 in a comet (made with the 43m telescope). The nitrogen budget in comets has been a puzzle. The evidence for the presence of NH_3 was indirect: 1) from observation of spectral features of NH and NH_2, which are believed to be photo-dissociation products of NH_3, and 2) from the interpretation of peaks near mass 17 found by the NMS and IMS experiments on the Giotto probe to comet Halley. However, neither method observes NH_3 directly and uniquely; and, the inferred amounts of NH_3 differed by an order of magnitude. (Previous radio attempts to directly detect NH_3 had failed.) We found that NH_3 has about 0.5and NH_2 studies, but not the current interpretation of the Giotto studies. Other of our Hyakutake studies which have progressed far enough for papers to be published are the observation of OH absorption during an occultation of a radio source and a search for 3mm wavelength continuum emission from the object. A great deal of data from the BIMA and the VLA remains to be fully processed. Data from Comet Hale-Bopp was obtained with the VLA, BIMA, the 100m single dish of the MPIfR near Bonn, Germany, the Australian Telescope National Facility (ATNF), the Five Colleges Radio Observatory (FCRAO), and the U.S. Naval Observatory at Flagstaff. Because Hale-Bopp was such a spectacularly productive comet, and because many observations could be planned, we have a vast amount of data to process. The most surprising result so far was the discovery of HCO^+ emission with BIMA. Although molecular ions have been seen in optical spectra of comet tails for many years, this was the first radio detection of a molecular ion in a cometary coma. The line profile shows a significant redward wing which suggests gas being swept away in the tail-ward direction; and, unlike HCN and most molecules, the emission was very extended and did not peak at the position of the nucleus. Further work on the chemical formation of HCO^+ and on analysis of its spatial distribution is underway based on combined BIMA and FCRAO data. The BIMA array provided images of relatively strong cometary lines like HCN is a few hours. Therefore we have a great deal of data which will be studied for temporal evolution (aided by photographs of the distribution of the CN radical obtained at Flagstaff). In addition CS images were made at BIMA which will be analyzed informed by data from other sulfur-containing molecules obtained at the NRAO 12m telescope. A series of occultations of radio sources was observed with the VLA beginning in September, 1996. We plan to continuing into Spring, 1998 as the comet moves southward with the ATNF. These studies provide information about the spatial distribution of OH, the primary photo-dissociation product of H_2O. A great deal of data remains to be analyzed.

PUBLICATIONS

Butler, B. J., Beasley, A. J., Wrobel, J. M., and Palmer, P. ''The Occultation of the QSO J0237+2848 by Comet C/1996 B2 (Hyakutake)'' A. J., **113**, 1429, 1997.

de Pater, I., Snyder, L. E., Mehringer, D. M., Wright, M., Palmer, P., and A'Hearn, M. ''BIMA Observations of Comet Hyakutake: Upper Limit to the 2.7mm Continuum Emission,'' Planet. Space Sci., 45, 731, 1997. Because of the nature of the recent work with comets Hyakutake and Hale – Bopp, it is probably useful to include the following:

Veal, J. M., Snyder, L. E.,Wright, M. C. H., Forster, J. R., Hoffman, W.,Pound, M., de Pater, I., Helfer, T., Plambeck,R. L., Engargiola, G., Wong, T., Woodney, L. M., A'Hearn, M. F., Palmer, P., and Kuan, Y.-J. ''Detection of HCO^+ in Comet C/1995 O1 (Hale-Bopp)'' IAU Circular 6575, (March 4, 1997).

Butler, B. J. and Palmer, P. ''Probing the OH in Hale-Bopp'' 1997, DPS meeting, July, 1997 (abstract only)

Woodney, L. M., A'Hearn, M. F., Fernandez, Y. R., Sherwin, A. K., Wellnitz, D. D., McMullin, J. P., Samarasinha, N., Farnham, T. L., Schleicher, D. G., Veal, J. M., Snyder, L. E., Wright, M. C. H., Forster, J. R., Hoffman, W., Pound, M., de Pater, I., Helfer, T., Plambeck, R. L., Palmer, P., Kuan, Y.-J. ''Temporal and Spatial Variability of Parent Molecules in Comet Hale-Bopp'' 1997 DPS Meeting, July, 1997 (abstract only).

4.9 Donald G. York

York continues his work on interstellar (IS) and intergalactic gas, and the relationship between the two. Colleagues in this work included Senior Research Associates P. Frisch, M. Hereld and D. Welty; graduate students L. Kao, C. Mallouris, G. Richards, C. Rockosi and D. Vanden Berk; and undergraduate D. Bruni. Graduate student Scott Severson, as part of a team led by M. Hereld, is completing his thesis on the impact of the comet with Jupiter in 1994. D. Vanden Berk received his Ph.D. in astronomy and astrophysics, and Damian Bruni received his B.S. in physics.

4.9.1 Projects

Throughout the year, York served as Director of the Sloan Digital Sky Survey (SDSS). The project is described in the report of the Apache Point Observatory (Astrophysical Research Consortium) in these reports. Frisch has continued her research into the properties of nearby interstellar gas and the interaction of the cloud surrounding the solar system with the heliosphere. The journey of the Sun through space has been investigated, with the conclusion that the galactic environment of the Sun has changed within the past $\sim 10^5$ years. With a simple model of the cloud surrounding the solar system that assumes that the cloud moves in a direction perpendicular to the surface, the Sun is found to have entered this cloud within the past $\sim$2,000 years. A comparison between the Lyα absorption line towards the nearby star α Cen and multifluid hydrodynamic theoretical models of the hydrogen pileup immediately outside of the nose region of the heliosphere shows that the data are consistent with the formation of a barely subsonic Mach number 0.9 bowshock around the heliosphere, with the temperature of the hydrogen pile-up a sensitive diagnostic of the Mach number (with Gayley, Zank, Pauls at Bartol, and Welty at Chicago). A comparison of the physical properties of the interstellar dust detected within the heliosphere and the interstellar dust in the cloud surrounding the solar system has been undertaken, with significantly different gas-to-dust mass ratios found from these two types of observations. Efforts to explain the microstructure in the dust distribution implied by these differences are underway (with Dorschner, Geiss, Greenberg, Gruen, Hoppe, Jones, Kraetschmer, Landgraf, Linde, Morfill, Reach, Slavin, Svestka, Witt, and Zank). The ionization properties in the cloud surrounding the solar system have been calculated using the photoionization code CLOUDY, and the results compared with the pick-up ion and anomalous cosmic ray data. The model and data compare favorably, but the ionization of He, Ne and other highly ionized species are found to be sensitive to the poorly constrained exteme ultraviolet radiation field. Helium is found to be $\sim$54% ionized, while hydrogen is found to be $\sim$35% ionized (with J. Slavin). The ways in which observations of the physical properties of the Local Bubble, Local Fluff, and Heliosphere are mutually interdependent have been summarized in a paper presented at IAU Colloquium No. 166, on the ''Local Bubble and Beyond.'' Welty [with Frisch, Hobbs, Mallouris, and York (Chicago), Federman (Toledo), Lauroesch (GSFC), Morton (Herzberg Inst.), Blades (STScI), Fitzpatrick (Villanova), and Jenkins (Princeton)] has continued to use a combination of high-resolution optical spectra and HST/GHRS echelle spectra to study the properties of individual interstellar clouds in various environments (local ISM, Galactic disk and halo, LMC and SMC, QSO absorption-line systems). High-resolution (1.4 km/s) spectra of Ca II have been obtained toward nearby stars in regions previously not well sampled, in order to characterize the kinematics and physical properties of the nearest IS clouds. Similar spectra of Na I have been obtained in some of those lines of sight to search for indications of small-scale dense structures in the local ISM. High-resolution spectra of Ca II and Na I have also been obtained (with E. Fitzpatrick) toward a small number of halo stars, in order to provide limits on T in the individual halo clouds and to model UV spectra obtained with GHRS. The spectra have revealed numerous components, many of which must arise in relatively cool gas; strong temporal variations in N(Na I) have been noted for an intermediate-velocity (presumably halo) component in one line of sight. Very high resolution

(0.3-0.6 km/sec) spectra of Ca I suggest that most of the observed Ca I is found in relatively cool gas, and that Ca II is the dominant ionization state of Ca there. The Ca I/Ca II ratio (indicative of the local electron density n_e does not appear to correlate with the fraction of hydrogen in molecular form, the average line of sight density, or the Ca depletion (all of which presumably depend on the local density n_H) –does n_e not depend on n_H? GHRS echelle spectra of 23 Ori, $_\gamma$CMa, and $_\zeta$Ori have yielded accurate electron densities, temperatures, and cloud thicknesses for the high-velocity ionized gas in those lines of sight, confirming that the gas is not in collisional ionization equilibrium. Observations of C II, C III, N II, N III, Si II, Si III, Al II, Al III, S II, S III, S IV, Fe II, and Fe III (combining data from IMAPS and GHRS) suggest that the total high- velocity N(H II) toward $_\zeta$Ori is about $7x10^{17}cm^{-2}$. Al and Fe appear to be depleted by about 0.8 dex, and Si may be depleted by about 0.4 dex – even in this presumably shocked gas at ~ -100 km/s. GHRS echelle and G160M spectra of the SMC star Sk 108 indicate that the relative gas-phase abundances of Zn II, Cr II, Fe II, Si II, Mn II, and Ni II are similar to those found in Galactic halo clouds and in some intermediate velocity clouds toward the LMC SN 1987A. Most of the intermediate velocity (Galactic) and LMC components toward SN 1987A, however, show relative abundances more similar to those seen for warm clouds in the Galactic disk. Comparison of these facts with the most complete set of relative abundances for those ions in QSO absorption line systems shows the latter to be like high velocity clouds in our Galaxy and most of the clouds in the SMC. The details indicate slight gas phase depletions and a base relative abundance set similar to Solar values, even though the overall depletions compared to hydrogen are 0.1 to 0.001 in the QSO absorbers. The clear signature of high values of [Si II]/[Fe II] expected in the earliest gas, owing to a dearth of Type I SNe, has not yet been found in our comparison. L. Kao is analyzing multi-band images of low z merging galaxies, obtained with the 3.5-meter telescope at Apache Point Observatory, then simulating their appearance at high redshift, for comparison with HST images of the latter. C. Mallouris is preparing target lists for the FUSE satellite (PI, W. Moos, JHU) and is searching for QSOs in the FIRST survey (R. Becker, UCSB; D. Helfand, Columbia; and R. White, STScI) that might have high fluxes at 1000A, where the satellite is uniquely sensitive. Other criteria include proximity of galaxy images, existence of previously known absorption lines, existence of 21 cm high velocity clouds on the sight lines, and models of the sight lines done with M. Lemoine (UC/CNRS). The goal of the observations is to measure the ratio [D/H] in a variety of low redshift sight lines in known environments. This work will be done in collaboration with J. Truran and S. Burles (UC). C. Rockosi is studying metallicity effects in well-studied clusters as manifested in the filter set of the SDSS. These clusters are too bright to study in the main SDSS survey. Eventually, the hope is to carry out a northern survey of bright stars in the SDSS filter set. York, A. Crotts (Columbia), Mallouris, Richards and Bruni are preparing another edition of the catalogue of QSO absorbers previously published in 1991. The catalogue lists observed properties of all known QSO absorption line systems (QSOALS) except for component fine structure below 100 km/sec. Care is taken to build up a coarse error array in the QSO continua so that limits can be placed on equivalent widths of any features in the redshift space covered by the observations. Data from different observers for the same system are tabulated. While no subjective judgment is made of individual measurements or redshifts from the literature, an objective grade is derived for each system that gives the probability it is real and indicates any reason for doubt. The new catalog includes radio brightness or limits (using FIRST where possible) and an expanded content on broad absorption line systems (BALS). Richards is using the catalog to re-examine the question of what percentage of the QSOALS could be associated with the QSO (i.e., not truly intergalactic), supplementing published work with spectra of new BALs from the 3.5-meter telescope at APO. D. Vanden Berk and J. Quashnock (UC) used the current version of the catalog to examine the evolution of medium scale clustering (1-16 Mpc) in the QSOALS sample. Strong evidence for evolution was found. D. Vanden Berk completed his thesis on Ly $alpha$ clouds in a narrow cone at the NGP (see references for a list of collaborators), using new HST observations and others in the HST archive. Thirteen QSOs within a 6 degree cone yielded a sample with $\langle z \rangle$ = 0.7, 588 absorption lines, 339 Ly $alpha$ systems, 5 CIV doublets, 1 MgII doublet and 19 heavy element-containing systems. Detailed correlation studies were done among the absorbers and between the absorbers and other samples (e.g., galaxies). The Ly $alpha$ lines were not randomly distributed in redshift. There are several clusters ($\sim$ 5 lines, over 20 h^{-1} Mpc) and more wide spread clustering on scales of 10 h^{-1} Mpc. Only 10-20% of the heavy element systems are in the Ly $alpha$ clusters. For standard models ($omega \sim 1$), it is excluded that the Ly $alpha$ absorbers with $0.5 < z < 1.0$ follow the same spiky distribution as galaxies (at $z < 0.4$) in the direction of the NGP. Sheet-like structures in Ly $alpha$ are also excluded. The Ly $alpha$ distribution could contain a component of objects clustered like metal line absorbers at the 40% level. Many of the Ly $alpha$ entities must be part of a more uniform distribution, however. Once the SDSS is producing spectra, hundreds of thousands of objects will be available for focused study, including QSOs with absorption lines in the spectra. Hereld and Richards are experimenting with the use of a large mass storage system (Chicago/Argonne Terabyte System, CATS) for storage, search and retrieval of such a system. Hereld works with other science groups in using the system for research in high energy physics, cosmic rays, meteorology, visualization of the turbulence calculations, cosmic background radiation and time resolved X-ray crystallography.

PUBLICATIONS

Frisch, P., J. Dorschner, J. Geiss, M. Greenberg, E. Grün, P. Hoppe, A. Jones, W. Krätschmer, M. Landgraf, T. Linde, G. Morfill, W. Reach, J. Slavin, J. Svestka, A. Witt, & G. Zank, 1997, ‘‘Dust in the Local Interstellar Wind’’ in preparation

Sanders, W. T., & and P. C. Frisch, 1997, ‘‘Workshop for

Continued Discussion of the Local Bubble'' in *The Local Bubble and Beyond, Proceedings of IAU Colloquium No. 166*, Lecture Notes in Physics Series Springer–Verlag, Eds. D. Breitschwerdt and M. Freyberg

Slavin, J. D., & P. C. Frisch, 1997, ''The Influence of the Local Bubble on the Ionization of the Local Interstellar Cloud'' in *The Local Bubble and Beyond, Proceedings of IAU Colloquium No. 166*, Lecture Notes in Physics Series, Springer–Verlag, Eds. D. Breitschwerdt and M. Freyberg

Frisch, P. C., 1997, ''Interstellar Matter and the Boundary Conditions of the Solar System,'' in *Advanced Composition Explorer Workshop, CalTech, Jan. 1997*, Space Science Reviews, submitted.

Frisch, P. C., 1997, ''The Local Bubble, Local Fluff, and Heliosphere,'' in *The Local Bubble and Beyond, Proceedings of IAU Colloquium No. 166*, Lecture Notes in Physics Series, Springer–Verlag, Eds. D. Breitschwerdt & M. Freyberg

Frisch, P. C., 1997, ''The Journey of the Sun,'' astro-ph/9705231

Frisch, P. C., 1996, '' LISM Structure: Fragmented Superbubble Shell?'' Space Sciences Reviews, 78, 213–222

Frisch, P. C., & J. Slavin, 1996, ''Relative Ionizations in the Nearest Interstellar Gas,'' Space Sciences Reviews, 78, 223–228

Breitschwerdt, D., R. Egger, M. J. Freyberg, P. C. Frisch, J. V. Vallerga, 1996, ''The Local Bubble: Origin and Evolution,'' Space Sciences Reviews, 78, 183–198

Welty, D.E. 1997, The Local Bubble and Beyond, in eds. D. Breitschwerdt & M. Freyberg, *High-Resolution Optical Observations of Diffuse Clouds*, (IAU Colloquium No. 166)

Gayley, K.G., Zank, G.P., Pauls, H.L., Frisch, P.C., & Welty, D.E. 1997, One- versus Two-Shock Heliosphere: Constraining Models with GHRS Lyman alpha Spectra toward alpha Centauri , ApJ, 487, 259

Welty, D. E., Lauroesch, J.T., Blades, J.C., Hobbs, L.M., & York, D.G. 1997, Interstellar Abundances in the Magellanic Clouds. I. GHRS Observations of the SMC Star Sk 108, ApJ, 489, 672

Gillespie, B., Lowenstein, R. F., & York, D. G. 1996. Remote Observing at Apache Point. In *New Observing Modes for the Next Century*. ASP Conference Series Volume 87. Eds., T.A. Boroson, J.K. Davies, & E.I. Robson.

Borra, E.F., Levesque, S., Beauchemin, M., Morton, D.C., Stoughton, C., Vanden Berk, D., Green A. F., York, D.G., & Crotts, A.P.S., 1996. Spectroscopy of Quasar Candidates Found with Slit Spectroscopy II: 5 Northern Fields, *Astrophysical Journal*, 111, 1456.

Vanden Berk, D.E., Quashnock, J.M., & York, D.G., 1996. An Excess of C IV Absorbers in Luminous QSO's: Evidence for Gravitational Lensing? *Astrophysical Journal*, 469, 78.

Quashnock, J.M., Vanden Berk, D. E., & York, D. G., 1996. High Redshift Superclustering of QSO Absorption Line Systems on $100h^{-1}$ Mpc Scales, *Astrophysical Journal Letters*, 472, L69.

Richards, G. T., Yanny, B., Annis, J., Newberg, H. J.M., McKay, T.A., York, D. G., & Fan, X. 1996. Quasar Photometry with SDSS Monitor Telescope. *Publications of the Astronomical Society of the Pacific*, 108, 641.

Timmes, F. X., Truran, J. W., Lauroesch, J. T. & York, D. G., 1996. Light Element Abundances from z = 0 to z = 5. *Astrophysical Journal*.

Vanden Berk, D., Lauroesch, J.T., Stoughton, C., Szalay, A., Koo, D.C., Crotts, A.P.S., Blades, J.C., Malott, A.L., Boyle, B.J., Broadhurst, T.J., & York, D.G., et.al., 1998. Clustering Properties of Low-Redshift QSO Absorption Line Systems Towards the Galactic Poles, *Astrophysical Journal Supplement Series*, in press.

5. WEBSITES

Updates on selected projects can be found on the Worldwide Web: UC Astronomy & Astrophysics: *http://astro.uchicago.edu/* Sloan Digital Sky Survey: *http://www-sdss.fnal.gov.8000/* Yerkes Observatory: *http://astro.uchicago.edu/Yerkes.html* Apache Point Observatory: *http://www.apo.nmsu.edu/*