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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.

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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 Br γ 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.

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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

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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 Galileos 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

The grounding of the Kuiper Airborne Observatory (KAO) has shifted the focus of Hildebrand's research group from airborne to ground-based observations and to instrument studies for future observations on SOFIA, the next airborne observatory. The last observations on the KAO (with guest observers M. Morris, J. Davidson, and M. Werner) provided strong incentives for future polarimetry on SOFIA. Observations of the Sickle, a thermal feature near the center of the Galaxy, showed the strongest and most uniform polarization yet observed anywhere in dust emission. Moreover the inferred direction of the magnetic field is exactly orthogonal to that in the adjacent non-thermal arcs. This is the most striking example among several anti-correlation's in field direction within 25 pc of the Galactic nucleus. In collaboration with J. Davidson, M. Dragovan, G. Novak, and S. Platt, Hildebrand is working on the design of a polarimeter for SOFIA. Tentative specifications include: Three passbands at 50, 100, and 200 microns (beam diameters 5,'' 10'', and 20'' arcsec); 1000 pixels on the sky; background limited detectors. Shortly after the last KAO flight the group began 350 micron polarimetry at the Caltech Submillimeter Observatory. The first observations with the new submillimeter instrument, Hertz, produced the most extensive map of polarization yet obtained at any submillimeter wavelength. The instrument and the results (on Orion) have been described in a paper listed below. Other activities of the group include near-infrared polarimetry at the Apache Point Observatory and participation in far-infrared polarimetry on ISO (A. Goodman, PI). Jessie Dotson's thesis will appear in ApJ in December 1996. David Schleuning will complete his thesis in 1996. Darren Dowell will complete his thesis in the spring of 1997. John Vaillancourt has joined the group as a beginning graduate student.

PUBLICATIONS

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

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, In press 1996.

Schleuning, D. A., Dowell, C. D., Hildebrand, R. H., & Platt. S. R. Hertz, A Submillimeter Polarimeter. PASP, in press 1996.

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 earths 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 usi ng 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 associates Walter Wild and James Larkin, and computer programmer Vijuna Scor.

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 characterization of 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. 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 QSOs 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. Most old and new plates for this program are in hand, with some additional new plates obtained at Las Campanas, and Kitt Peak in the past year. Our study of Pal 5 has been completed and a paper is in preparation, while some progress has been made on the studies of Pal 13, Pal 15, and Arp 2. A. Schweitzer (Wisconsin) completed her thesis research working with Cudworth and received her Ph.D. from UW. This work included proper motion studies to derive membership and absolute proper motions of the dwarf spheroidal galaxies Sculptor and Ursa Minor. Their study of Scl was published during the report year. The proper motion shows that Scl is definitely not associated with the Magellanic stream, but could be associated with a stream including Fornax. Their study of UMi is essentially complete and a journal paper is in preparation. 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. Rees (Penn) spent the summer at Yerkes Observatory continuing his research deriving distances to globular clusters by comparing proper motion and radial velocity dispersions. In the course of the Ursa Minor study a systematic error was found infecting measurements made with the PDS microdensitometer at MADRAF which has been used for nearly all of the Yerkes astrometric program's work in the past 15 years. The size of the systematic error is so small, however, that we could only find it in the unusually excellent plate material of the UMi project. Our checks of other measurements show that it has probably always been present, but that it has been overwhelmed by random errors in all of our published cluster studies. Cudworth devoted considerable time to removing the systematic error from the UMi measurements and developing a strategy for correcting it in future work.

PUBLICATIONS

Schweitzer, A. E., Cudworth, K. M., Majewski, S. R., & Suntzeff, N. B. ''The Absolute Proper Motion and a Membership Survey of the Sculptor Dwarf Spheroidal Galaxy,'' AJ, 110, 2747, 1995

Schweitzer, A. E. & Cudworth, K. M. ''Ursa Minor Dwarf Spheroidal Galaxy Proper Motion Survey- Cleaning up the Color-Magnitude Diagram,'' BAAS, 27, 1297, 1995

Finlay, J., Noriega-Crespo, A., Friel, E. D., & Cudworth, K. M. ''Galactic Orbits and the Survival of Old Open Clusters,'' BAAS, 27, 1437, 1995

Schweitzer, A. E. & Cudworth, K. M. ''Proper Motions of Dwarf Spheroidal Galaxies,'' in ASP Conf. Ser. 92 *The Formation of the Galactic Halo*'', eds. H. Morrison & A. Sarajedini, p. 532, 1996

Rees, R. F. ''Astrometric Distances to Globular Clusters: New Results,'' in ASP Conf. Ser. 92 *The Formation of the Galactic Halo*, eds. H. Morrison & A. Sarajedini, p. 289, 1996

Schweitzer, A. E. & Cudworth, K. M. ''The Absolute Proper Motion of the Ursa Minor Dwarf Spheroidal Galaxy,'' BAAS, 28, 835, 1996

4.2 Douglas K. Duncan

Duncan is the American Astronomical Society National Education Coordinator and the Director of the Ameritech Space News Center at Adler Planetarium. 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); determination of the B11/B10 isotopic ratio (with L.M. Rebull, S. Johansson, J. Thorburn, D. Schramm, and B. Fields); the NLTE effects on boron abundances (with D. Kiselman and J. Thorburn); and work continues on the evolution of rotation rates of late-type stars (with L.M. Rebull).

4.3 Doyal A. Harper, Jr.

Harper and his research group use Infrared and submillimeter techniques to study processes related to the formation and evolution of stars, planetary systems, and galaxies. Harper continues as Director of the Center for Astrophysical Research in Antarctica (CARA), a National Science Foundation Science and Technology Center. CA-RA's mission is to study the evolution of structure in the universe by exploiting the unique observing conditions for infrared and submillimeter astronomy on the Antarctic Polar Plateau. CARA researchers have established an observatory at the South Pole and are installing a series of telescopes which will study millimeter-wavelength radiation from the cosmic microwave background radiation, infrared emission from distant galaxies, and infrared and submillimeter emission from interstellar matter in Galactic and extragalactic star-forming regions. The Center also pursues a vigorous program of educational outreach and technology transfer aimed at maximizing the benefits of its research for the nation's human and technological infrastructure.

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

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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. 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.

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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

The Oka research group observed the Jupiter-SL9 collision using UKIRT (United Kingdom Infrared Telescope) at Mauna Kea, Hawaii to observe infrared spectra of H^{3+} and other simple molecules in the Jovian ionosphere and to study the chemical effect of the impacts. There was a concern that the effect of the impacts would be miniscule and no major change would occur to the spectra, but a humongous variation of the spectral pattern after impacts was seen, indicating wide ranging violent chemical effects. Collaboration continues with Walter Wild and Lancelot Kao in studying Jovian planets in the near-infrared, using GRIM II at APO. More recently, they are studying the possibility of building an infrared camera to be mounted at the 41-in reflector at Yerkes Observatory to study Jovian planets and star formation regions.

4.8 Patrick Palmer

Work continued on several projects: molecules in the interstellar medium, radar astrometry of asteroids, and cometary problems. Most of these projects have involved data obtained with the Very Large Array.

4.8.1 Interstellar Medium

We (with D. Mehringer and W. M. Goss) have continued our studies of the Galactic center region. One aspect is especially puzzling: the presence of 6 cm H_2CO masers. At the time of our first observations of the Galactic center giant HII region Sgr B2, it was one of the three known objects in the Galaxy with associated H_2CO masers. However, Sgr B2 had five distinct regions of maser activity. A theoretical explanation for the H_2CO masers had been offered which seemed promising, partly because it required rather special geometrical conditions, as might be expected for a rare phenomenon. We carefully re-observed Sgr B2, and discovered four more regions of maser activity, and because we determined the positions of all of the masers very accurately, we showed that the explanation offered could not explain at least the majority of the masers there. Next, we tried to improve the sample size. We carried out a very sensitive search for masers in 22 additional Galactic star forming regions – and found none! Either the lifetime of the H_2CO masers is very short, or they can only exist in a narrow range of physical conditions. It is strange that nine would exist in one region while only two others are found in the rest of the Galaxy. We are pursuing this problem. Very recently, we searched for the analogous H_2CO masers at 2 cm. Data from these observations will be processed this summer.

4.8.2 Near earth asteroids

Near earth asteroids are interesting for a number of reasons. One of the major problems is to get extremely accurate positional measurements so that future orbits can be predicted with high accuracy. Many are detectable only when near the Earth, so data is obtained for only a short arc of the orbit. Radar astronomy provides very accurate line-of sight information, but the location of an asteroid in the plane of the sky is usually determined optical astrometry (which much less as accurate for moving objects than it is for stars, for example.) Last June, we (with S. Ostro, S. Hudson, I. de Pater and L. Snyder) began an experiment to see if we could use the positional accuracy of the VLA to determine the plane of the sky positions of radar-illuminated asteroids. The goal was to reduce the error ellipsoid for the asteroid's instantaneous position to a size smaller than the asteroid itself. We observed 1991 JX on three dates. Only one was entirely successful (one more day will be usable after some software corrections are made). The preliminary result is that our error bars for the plane of the sky position are $\sim$ 0.02 arcseconds, about a factor of 50 smaller than the error in optical determinations. (The very accurate centroid position is also an extremely valuable constraint in range-Doppler imaging which permits resolution of 10's of meters for near earth asteroids in situations with adequate signal - to - noise.)

4.8.3 Comets

Much of the progress in cometary science has been made from studies of the rare bright comets. In March, 1996, comet Hyakutake approached with 0.11 AU of the Earth and was a spectacular sight. Since its discovery at the end of January, this object has dominated our research efforts with planning, carrying out observations, and analysis. These involved observations at the VLA and with the Berkeley - Illinois - Maryland array (with L. Snyder and I. de Pater), and other observations at the VLA, the NRAO 43 meter telescope in Green Bank West Virginia, and the NRAO 12-meter telescope on Kitt Peak (with A. Wootten, B. Butler, D. Bocklée-Morvan, D. Depois, and D. K. Yeomans). The only result ready to report at present is for a study of NH_3. While NH_3 is believed to contain a significant fraction of the N in comets , its direct detection has been elusive. Most of the abundance estimates were indirect ones made from optical NH_2 lines (assuming that NH_3 is the only parent of NH_2). These fell in the range 0.2% – 0.5% (relative to water). A single radio observation of NH_3 in comet IRAS-Araki- Alcock in 1983 suggested an abundance $\sim$ 10%; analysis of *in situ* results from the Giotto probe to comet Halley in 1986 yielded results in the range 1% — 2%. However, the previous radio measurement had poor signal to noise and possible instrumental problems; and, the analysis of the Giotto mass spectrometer results does not provide a direct measurement of NH_3, but relies on a chemical model to sort out the fractional contribution of NH_3 in this mass range. We made an unambiguous detection of two NH_3 lines in comet Hyakutake on the night of March 24/25. These lines yielded a ratio of 0.3%, very much in line with the optical determination in a number of comets.

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4.9 Donald G. York

York continues his work on interstellar and intergalactic gas, and the relationships between the two fields. Colleagues in this work include senior research associates Priscilla Frisch and Daniel Welty; graduate students Lancelot Kao, Chris Mallouris, Connie Rockosi, Scott Severson, and Daniel Vanden Berk; and undergraduate Damian Bruni. Jim Fowler received his Ph.D. in June 1996; Varsha Kulkarni has completed her dissertation research and will receive her Ph.D. at the end of 1996.

4.9.1 Projects

Priscilla Frisch continues her study of nearby interstellar medium and the cloud surrounding the solar system. Welty [with Frisch, Hobbs, Lauroesch, Trapero, and York (Chicago), Federman (Toledo), Morton (Herzberg Inst.), Blades (STScI), and Fitzpatrick, Jenkins, and Spitzer (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). A high-resolution (0.3-1.2 km s^{-1}) survey of interstellar Ca II (Welty, Morton, & Hobbs 1996) revealed complex component structure in many cases, similar to that found in a previous survey of Na I. Comparison of Na I and Ca II line widths, however, suggests that the Ca II is more widely distributed, even for corresponding components at the same velocity. The interplay between the strong effects of Ca ionization balance and Ca depletion, for different types of neutral gas, can explain the similarities between the line profiles seen for Ca II and for various dominant first ions of less depleted elements. Comparisons of new high-resolution spectra of Ca I, Ca II, and K I are enabling individual component estimates for both relative electron densities and the abundances of other neutral and singly ionized species to be determined from lower resolution GHRS echelle spectra, for a number of lines of sight. The relatively low density derived from an analysis of the C I fine-structure excitation equilibrium for the two main low-velocity components toward 23 Ori suggests that the surprisingly strong CH lines there are due to the same non-thermal process that has produced the observed CH^+ (Federman, Welty, & Cardelli 1997). New GHRS echelle spectra of 23 Ori, τ CMa, and ζ 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 (as concluded by Trapero *et al.* 1996). 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) will yield detailed information on grain survival in the shocked high-velocity gas toward ζ Ori and 23 Ori. 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 and LMC components toward SN 1987A, however, show relative abundances more similar to those seen for warm clouds in the Galactic disk. Comparisons of the relative abundances found in various Galactic environments with those in the lower metallicity LMC and SMC should aid in the interpretation of the relative abundances observed in QSO absorption-line systems (Lauroesch *et al.* 1996). Scott Severson continues his work in the Near Infrared Experimental Astrophysics Group (better known as NIR.) He has been involved with the design, completion, delivery and scientific use of two near infrared instruments: GRIM I, and GRIM II. Dan Vanden Berk is continuing to focus on the clustering properties of QSO absorption line systems and their relation to galaxies. His thesis observations of low-redshift absorbers at the galactic poles, observed with HST, are nearly complete, and the analysis of the data is underway. The distribution of the absorbers is being compared to that of the galaxies in the same relatively narrow cones to see how the clustering properties of the two populations are related. Dan is leading the ongoing compilation of a large, continually-updated catalog of QSO absorbers drawn from the literature, which is being analyzed for the signature of clustering. Using this catalog, absorber clustering on scales up to 100 Mpc/h (comoving) has been detected at high redshift (Quashnock, Vanden Berk, & York 1996, ApJL, in press). On smaller scales, the clustering of absorbers in the catalog has been shown to be quite similar to that of low-redshift galaxies. In addition, the evolution of the absorber clustering – which has implications for structure formation and cosmology – has begun to be studied. Strong evidence has been uncovered that a large fraction of QSOs searched for absorption lines are gravitationally lensed by mass associated with the absorbers (Vanden Berk, Quashnock, York, & Yanny 1996, ApJ 469, 78). These results will help in understanding how well absorbers can be used as unbiased tracers of matter in the universe. Lancelot Kao is studying the importance of galaxy mergers as a function of redshift. He has obtained most of his dissertation data (multiband images of local mergers and interacting galaxies) from Apache Point Observatory (APO). Current work is focused in data reduction and simulation of the appearance at high redshift as seen by HST and various ground-based systems. This work should enable an evaluation of incompleteness effects on counts of mergers in assessing their relative importance at different redshifts. He is collaborating with Takeshi Oka and Walter Wild in studying Jovian planets in the near-infrared, using GRIM II at APO. More recently, they are studying the possibility of building an infrared camera to be mounted at the 41-in reflector at Yerkes Observatory to study Jovian planets and star formation regions.

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4.9.2 Sloan Digital Sky Survey

York continues as Director of the Sloan Digital Sky Survey (SDSS) project, the goal of which is to create a three-dimensional map of one million galaxies in the North Galactic Cap. The project involves instrumenting a 2.5-m telescope with a CCD camera (30 CCDs, 50 mm in linear dimension, arranged to produce 5-color drift scans of the sky) and two fiber-fed spectrographs. The spectrographs obtain about 600 spectra simultaneously for a sample of galaxies and QSOs selected from the multi-color drift scans. The major hardware and software components were completed in 1996, and the survey is expected to last about five years, after a year of commissioning activities. Work has continued this year on the mechanical telescope parts, which were assembled at Apache Point Observatory (APO) near Sunspot, N.M. in September 1995. Polishing has been finished on the primary and secondary mirrors, which have been aluminized and delivered to APO. The distortion corrector for the three-degree field of the telescope, to which the CCD dewars attach, is complete, and the other field corrector common to both instruments is nearing completion. The instruments are in final assembly, and their delivery and installation at APO is expected during late 1996 through early 1997. The project will acquire over 20 terabytes of data. The data acquisition hardware and software, and the data reduction software, are the prime responsibility of Fermi National Accelerator Laboratory (FNAL). Science software from specialists will be integrated into the pipeline. The data will be processed and archived at FNAL. The data acquisition system is already being delivered to APO. The computer hardware for the pipeline processing has been procured. A number of generations of the processing software have been completed, and the final version is to be completed after several months of observing with the entire system. The project is being carried out by the Astrophysical Research Consortium, whose members are the University of Chicago (UC), the Institute for Advanced Study (IAS), Johns Hopkins University (JHU), New Mexico State University (NMSU), Princeton University (PU), University of Washington (UW), and Washington State University (WSU). Participants in the Sloan Digital Sky Survey include all of these institutions (except NMSU and WSU), plus FNAL, a group of astronomers in Japan, the Japanese Participation Group (JPG), and the United States Naval Observatory (USNO). John Peoples (FNAL) is the chairman of the ARC sub-Board for the SDSS, York is director, Jeffrey Pier (USNO) is project manager, James Gunn (PU) is the project scientist, Richard Kron (UC/FNAL) is the survey director, and Stephen Kent (UC/FNAL) is the computer coordinator. The telescope, optics, and infrastructure are being developed by the UW engineering group, under Patrick Waddell. The spectrographs are being built at Johns Hopkins University under the supervision of Alan Uomoto, and the camera is being built at Princeton University under the supervision of James Gunn. For more on the Apache Point Observatory, please see the accompanying report of the Astrophysical Research Consortium.

5. WEBSITES

Updates on selected projects can be found on the World-wide 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/*