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This report covers the period of 1 July 1995 — 30 June 1996.

1. PERSONNEL

During the reporting year, the Research Staff was joined by Alex Lazarian (from Cambridge and University of Texas). Neil Tyson was named the Frederick P. Rose Director of the Hayden Planetarium. The following Research Staff members completed their appointments in the department and accepted new positions: N. Ellman (Yale) and S. Malhotra (IPAC).

Honors were conferred upon several members of the department. Martin Schwarzschild was elected Foreign Member of the Royal Society, London. Michael Strauss was awarded the Newton Lacy Pierce Prize of the AAS ''for his leadership in work on cosmic structure.'' Ed Jenkins was elected Vice President of the AAS.

Visitors staying over one month included: P. Artymowicz (Stockholm Observatory), P. Brand (Royal Observatory, Edinburgh), T. Chmaj (Copernicus Center, Warsaw), L. Guzzo (Observatorio Astronomico di Brera, Merate), A. Jorissen (Brussels), M. Kirage (Warsaw University Observatory), J. Kaluzny (Copernicus Center, Warsaw), T. Padmanabhan (IUCAA, Pune), M.-G. Park (Korea), D. Ryu (Korea), and R. Wijers (Cambridge).

The Spring Lecturer was George Preston from the Carnegie Institution, who presented a series of lectures on the stellar content of the Milky Way.

2. RESEARCH PROGRAM

2.1 Galaxies, Quasars and Cosmology

N. Bahcall, in collaboration with S.P. Oh (graduate student), determined the peculiar velocity distribution function of clusters of galaxies using an accurate sample of cluster velocities (from Giovanelli and Haynes, 1996) based on Tully-Fisher distances of Sc galaxies. The observed velocity function does not exhibit a tail of high peculiar motion clusters, in contrast with previous samples with considerably larger velocity uncertainties. The current results indicate a low probability of $\leqslant 5\%$ of finding clusters with one-dimensional peculiar motions greater than $\sim$600km s^{-1}. The root-mean-square cluster peculiar velocity is 293 ± 28km s^{-1}.

The observed cluster velocity distribution function was compared with expectations from different cosmological models. The absence of a high-velocity tail in the observed function is found to be most consistent with a low mass-density ($\Omega \sim 0.3$) CDM model and is inconsistent at the $>3\sigma$ level with $\Omega = 1.0$ CDM and HDM models. The rms one-dimensional cluster peculiar velocities in these models correspond, respectively, to 314, 516, and 632 km s^{-1} (when convolved with the observational uncertainties). Comparison with the observed rms cluster velocity of 293 $\pm$ 28 kms^{-1} further supports the low-density CDM model.

N. Bahcall, R. Cen, L. Lubin (graduate student), and J.P. Ostriker compared observations of the baryon fraction and the velocity-temperature relation in clusters of galaxies with expectations from cosmological models using large-scale hydrodynamic simulations. Two cosmological models were investigated: Standard ($\Omega = 1$) and flat low-density ($\Omega = 0.45, \Lambda = 0.55$) CDM models, normalized to the COBE background fluctuations. The observed properties of clusters include the velocity dispersion versus temperature relation, the gas mass versus total mass relation, and the gas mass fraction versus velocity dispersion relation. The results show that while both cosmological models reproduce well the *shape* of these observed functions, only low-density CDM can reproduce the observed *amplitudes*. The models show that $\sigma \sim T^{0.6 \pm 0.1}$, as expected for approximate hydrostatic equilibrium with the cluster potential, and that the ratio of gas to total mass in clusters is approximately constant for both models. The *amplitude* of the relations, however, differs significantly between the two models. The low-density CDM model reproduces well the *average* observed relation for clusters of $M_{\rm gas} = (0.13 \pm 0.02) M h_{50}^{-1.5}$, while $\Omega = 1$ CDM yields a gas mass that is three times too low ($M_{\rm gas} = 0.045 \pm 0.004 M h_{50}^{-1.5}$). Both gas and total mass are measured within a fiducial radius of 1.5h^{-1}Mpc. The cluster gas mass fraction reflects approximately the baryon fraction in the models, Ω_b / Ω. An $\Omega = 1$ model produces too few baryons in clusters compared with observations. Scaling the results as a function of Ω, the authors find that a low-density CDM model, with $\Omega \sim 0.3$, best reproduces the observed mean baryon fraction in clusters.

N. Bahcall, in collaboration with L. Lubin and V. Dorman (graduate students), used optical and X-ray mass determination of galaxies, groups and clusters of galaxies to investigate the amount and the location of dark matter. The results suggest that most of the dark matter may reside in very large halos around galaxies, typically extending to $\sim$ 200 kpc for bright galaxies. They show that the mass-to-light ratio of galaxy systems does not increase significantly with linear scale beyond the very large halos suggested for individual galaxies. Rather, the total mass of large scale systems such as groups and rich clusters of galaxies, even superclusters, can on average be accounted for by the total mass of their member galaxies, including their large halos (which may be stripped off in the dense cluster environment but still remain in the clusters) plus the mass of the hot intracluster gas. This conclusion also suggests that we may live in a low-density universe with $\Omega \sim 0.2 - 0.3$.

N. Bahcall reviewed some of the unsolved problems in the study of large-scale structure of the universe and summarized goals for their resolution. Bahcall also reviewed the topics of clusters of galaxies, superclusters, and voids, and dark-matter in the universe, including both observations as well as cosmological implications.

R. Cen and J.P. Ostriker, in collaboration with H. Kang (Korea) and D. Ryu (Korea), present a new treatment of two popular models for the growth of structure, examining the X-ray emission from hot gas with allowance for spectral line emission from various atomic species, primarily ''metals.'' The X-ray emission from the bright cluster sources is not significantly changed from prior work and shows the CDM $+\Lambda$ model (LCDM) to be consistent but the standard, COBE normalized model (SCDM) to be inconsistent with existing observations – even after allowance for the still considerable numerical modeling uncertainties. They find one important new result: radiation in the softer 0.5-1.0keV band is predominantly emitted by gas far from cluster centers (hence ''background''). This background emission dominates over the cluster emission below 1keV and observations of it should show clear spectral signatures indicating its origin. In particular the ''iron blend'' should be seen prominently in this spectral bin from cosmic background hot gas at high galactic latitudes and should show shadowing against the SMC indicating its extragalactic origin. Certain OVII lines also provide a signature of this gas which emits a spectrum characteristic of $10^{6.6\pm0.6}$ K gas. Recent ASCA observations of the X-ray background tentatively indicate the presence of a component with the predicted spectral features.

R. Cen and J.P. Ostriker have computed a variety of cosmological models into the extreme nonlinear phase to enable comparisons with observations, including a current state-of-the-art treatment of hydrodynamical processes, heating and cooling. The results for such a suite of currently interesting models are summarized and compared. All models have a mean ($z=0$) temperature of $10^{4.5}$ – $10^{5.5}$ K, set essentially by photoheating processes. Most gas is in one of two components: either at the photoheating floor of $10^{4.5}$ K and primarily in low density regions or else shock-heated to 10^5 – 10^6K and in regions of moderate overdensity (in caustics and near groups and clusters). It will be a major observational challenge to observationally detect this second, abundant component as it is neither an efficient radiator nor absorber. About 2% to 10% of the baryons cool and collapse into galaxies forming on caustics and migrating to clusters. About 1%-2% of baryons are in the very hot X-ray-emitting gas near cluster cores, in good agreement with observations. These correspondences between the simulations and the real world imply that there is some significant truth to the underlying standard scenarios for the growth of structure. The differences among model predictions may point out the path to the correct model. For COBE normalized models the most relevant differences concern the epoch of structure formation. In the open variants having $\Omega=0.3$, with or without a cosmological constant, structure formation on galactic scales is well advanced at redshift $z=5$, and reionization occurs early. But if observations require models for which most galaxy formation occurs more recently than $z=2$, then the flat $\Omega=1$ models are to be preferred. The velocity dispersion on the $1h^{-1}$Mpc scale also provides a strong discriminant with, as expected, the $\Omega=1$ models giving a much higher (perhaps too high) value for that statistic.

R. Cen, J.R. Gott, and J.P. Ostriker studied the topology of large scale structure as a function of galaxy type using the genus statistic. In hydrodynamical cosmological CDM simulations, galaxies form on caustic surfaces (Zeldovich pancakes) and then slowly drain onto filaments and clusters. The earliest forming galaxies in the simulations (defined as ''ellipticals'') are thus seen at the present epoch preferentially in clusters (tending toward a meatball topology), while the latest forming galaxies (defined as ''spiral'') are seen currently in a spongelike topology. The topology is measured by the genus (= number of ''donut'' holes−number of isolated regions) of the smoothed density-contour surfaces. The measured genus curve for all galaxies as a function of density obeys approximately the theoretical curve expected for random-phase initial conditions, but the early forming elliptical galaxies show a shift toward a meatball topology relative to the late forming spirals. Simulations using standard biasing schemes fail to show such an effect. Large observational samples separated by galaxy type could be used to test for this effect.

R. Cen, J.P. Ostriker and F.J. Summers, in collaboration with T. Padmanabhan (IUCAA, Pune), studied the nonlinear clustering of dark matter particles in an expanding universe using N-body simulations. One can gain some insight into this complex problem if simple relations between physical quantities in the linear and nonlinear regimes can be extracted from the results of N-body simulations. They investigate the relation between the mean relative pair velocities and the mean correlation function and other closely related issues in detail for the case of six different power spectra: power laws with spectral indexes $n=-2,-1$, cold dark matter (CDM), and hot dark matter models with density parameter $\Omega=1$; CDM including a cosmological constant (Λ) with $\Omega_{\rm CDM}=0.4$, $\Omega_\Lambda=0.6$; and an $n=-1$ model with $\Omega=0.1$. They find that: (i) Power law spectra lead to self-similar evolution in an $\Omega=1$ universe. (ii) Stable clustering does not hold in an $\Omega=1$ universe to the extent our simulations can ascertain. (iii) Stable clustering is a better approximation in the case of an $\Omega<1$ universe in which structure formation freezes out at some low redshift. (iv) The relation between dimensionless pair velocity and the mean correlation function, $\bar{\xi}$, is only approximately independent of the shape of the power spectrum. At the nonlinear end, the asymptotic value of the dimensionless pair velocity decreases with increasing small scale power, because the stable clustering assumption is not universally true. (v) The relation between the evolved $\bar{\xi}$ and the linear regime $\bar{\xi}$ is also not universal but shows a weak spectrum dependence. Simple theoretical arguments for these conclusions are presented.

R. Cen and J.P. Ostriker, in collaboration with J. Wambsganss (Potsdam) described in detail a new method to trace light rays through an essentially three dimensional mass distribution up to high redshift. As an example, the method is applied to a standard cold dark matter universe. A variety of results are obtained, some of them statistical in nature, others from rather detailed case studies of individual ''lines of sight.'' Among the former are the frequency of multiply imaged quasars, the distribution of separation of the multiple quasars, and the redshift distribution of lenses, all as a function of quasar redshift. Various effects are considered, ranging from very weak lensing up to highly magnified multiple images of high redshift objects. Applied to extended sources, i.e., galaxies, this ranges from slight deformations of the shapes, only measurable in a big ensemble, through tangentially aligned arclets up to giant luminous arcs. The weak coherent shear fields produced by lensing of large scale structure can be studied in directions that are devoid of large mass concentrations as well as the strong lensing around massive clusters of galaxies. Gravitational lensing directly measures mass density fluctuations along the line of sight to very distant objects. No assumptions need to be made concerning bias, the ratio of fluctuations in galaxy density to mass density. Hence lensing is a good tool to study the universe at medium and high redshifts. Cosmological models – normalized to the universe at redshift zero – differ considerably in their predictions for the mass distributions at these distance scales. Therefore lensing is a powerful tool to distinguish between various cosmological models. Our ultimate goal is to apply this method to a number of cosmogonic models in order to study their gravitational lensing effects and be able to eliminate some models whose properties are very different from the properties of the observed universe.

R. Cen, J.P. Ostriker, G. Xu (graduate student), and J. Wambsganss (Potsdam), examined the effects of weak gravitational lensing by large-scale structure on the determination of the cosmological deceleration parameter q_0. They found that for true standard candles the lensing induced dispersions of 0.04 and 0.02 mag at redshift $z=1$ and $z=0.5$, respectively, in a COBE-normalized cold dark matter universe with $\Omega_0=0.40, \Lambda_0=0.6, H=65$km/s/Mpc and $\sigma_8=0.79$. It is shown that one would observe $q_0=0.44^{+0.17}_{-0.05}$ and $q_0=0.45^{+0.10}_{-0.03}$ (the error bars are 2σ limits) with standard candles with zero intrinsic dispersion at redshift $z=1$ and $z=0.5$, respectively, compared to the truth of $q_0=0.40$ in this case, i.e., a 10% error in q_0 will be made. A standard COBE normalized $\Omega_0=1$ CDM model would produce three times as much variance and a mixed (hot and cold) dark matter model would lead to an intermediate result. One unique signature of this dispersion effect is its non-Gaussianity. Although the lensing-induced dispersion at lower redshift is still significantly smaller than the currently best observed (total) dispersion of 0.12 mag in a sample of type Ia supernovae, selected with the multicolor light curve shape method, it becomes significant at higher redshift. They show that there is an optimal redshift, in the range $z\sim0.5-2.0$ depending on the amplitude of the intrinsic dispersion of the standard candles, at which q_0 can be most accurately determined.

R. Cen and J.P. Ostriker, in collaboration with G.L. Bryan (NCSA), M.L. Norman (NCSA), and J.M. Stone (U.Md), described a hybrid scheme for cosmological simulations that incorporates a Lagrangian particle-mesh (PM) algorithm to follow the collisionless matter with the higher order accurate piecewise parabolic method (PPM) to solve the equations of gas dynamics. Both components interact through the gravitational potential, which requires the solution of Poisson's equation, here done by Fourier transforms. Due to the vast range of conditions that occur in cosmological flows (pressure difference of up to fourteen orders of magnitude), a number of additions and modifications to PPM were required to produce accurate results. These are described, as are a suite of cosmological tests.

R. Cen and R.A. Simcoe (undergraduate), performed a detailed analysis of the Lyman-α clouds produced by cosmological hydrodynamic simulations of a spatially flat cold dark matter universe with a non-zero cosmological constant. They find a very wide variety of structures, ranging from roundish high density regions with $N_{\rm HI}>10^{16}$cm^{-2}, to filamentary and sheet-like structures with column densities below 10^{14}cm^{-2}. The most common shape of the Lyα clouds found in the simulation resembles a cigar squashed in the longitudinal direction. Furthermore, these Lyα clouds range in size from several kiloparsecs to about a hundred kiloparsecs, indicating that if simple models with a single population of uniformly sized spheres (or other shapes) fit observations, this is only by coincidence. They showed that the method of inferring the sizes of Lyα clouds using observations of double quasar sightlines is only meaningful (in terms of setting lower limits on cloud sizes) when the sightline separations are small ($\Delta r<50h^{-1}$kpc). Finally, they conjectured that high column density Lyα clouds ($N_{\rm HI}>10^{16}$ cm^{-2}) may be progenitors of faint blue galaxies at lower redshift, because the correlation length of these Lyα clouds (extrapolated to lower redshift) resembles that of the observed faint blue galaxies, and their masses are close to those of starburst dwarf galaxies proposed by Babul & Rees.

R. Cen, J.P. Ostriker, J. Miralda-Escudé (IAS), and M. Rauch (Caltech), used an Eulerian hydrodynamic cosmological simulation to model the Lyα forest in a spatially flat, COBE-normalized, cold dark matter model with $\Omega=0.4$. They found that the intergalactic, photoionized gas collapses into sheet-like and filamentary structures with HI having characteristics similar to the observed Lyα forest. A typical filament is $\sim 1h^{-1}$ Mpc long with thickness $\sim 50-100h^{-1}$kpc (in proper units), and baryonic mass $\sim 10^{10}h^{-1}M_\odot$. (In comparison the cell size is (2.5,9) h^{-1}kpc in the two simulations.) The gas temperature is in the range 10^4-10^5K and increasing with time as structures with larger velocities collapse gravitationally. The predicted distributions of column densities, β-parameters and equivalent widths of the Lyα forest clouds agree reasonably with observations, and their evolution is consistent with the observed evolution, if the ionizing background has an approximately constant intensity between z=2 and z=4. A new method of identifying absorption lines as contiguous regions in the spectrum below a fixed flux threshold is suggested given that the Lyα spectra arise from a continuous density field of neutral hydrogen rather than discrete clouds. They also predict the distribution of transmitted flux and its correlation along a spectrum and on parallel spectra, and the He II flux decrement as a function of redshift. A correlation length of $\sim 80h^{-1}$ kpc perpendicular to the line of sight is predicted for features in the Lyα forest.

In order to reproduce the observed number of lines and average flux transmission, the baryon content of the clouds may need to be significantly higher than in previous models because of the predicted low densities and large volumefilling factors. If the background intensity $J_{\rm HI}$ is at least that predicted from the observed quasars, Ω_b needs to be as high as $\sim 0.025h^{-2}$, higher than expected by light element nucleosynthesis; the model also predicts that most of baryons at $z>2$ are in Lyα clouds, and that the rate at which the baryons move to more overdense regions is slow. A large fraction of the baryons which are not observed at present in galaxies might be intergalactic gas in the currently collapsing structures, with $T\sim 10^5-10^6$K.

R. Cen, using a large set of N-body simulations occupying a large volume in the four dimensional phase space $(\sigma_8,\Omega_0,\Lambda_0,\gamma)$, showed that the abundance of rich clusters of galaxies can be described as a smooth analytic elementary function of one parameter, X_{cl}, which in turn depends on the four parameters in a very simple way. This relation enables us to compute the abundance of rich clusters of galaxies at any redshift for any cosmological model analytically, without resorting to expensive N-body calculations.

Two implications are worth stressing. First, it seems that a tilt of the spectrum from the Harrison-Zeldovich value of unity is required in order for CDM-like models to fit both COBE and galaxy cluster observations. Second, the evolution of rich clusters of galaxies will probably provide the single most strong discriminant of Ω_0. Normalizing models to the present day rich cluster abundance, it is predicted that there should exist (0.004, 38, 4404) clusters with richness two and above at redshift two in three model universes with $(\Omega_0,\Lambda_0)=$(1.0, 0.0), (0.3,0.7), (0.3,0.0). ROSAT and future X-ray missions as well as large redshift surveys such as the Sloan Digital Sky Survey should provide a test.

N. Gnedin, together with E. Bertschinger (MIT), worked on constructing a new self-gravitating hydrodynamic code. The project was motivated by the extensive study of the SLH cosmological hydrodynamic code that was developed in Gnedin's thesis. Gnedin and Bertschinger showed that the Moving Mesh Gravity solver, previously used in the SLH code, had generic errors that could negate the results of a simulation. Some of those errors but not all, were identified and cured. The gravity solver in the SLH code was then replaced with the well tested P3M solver. While incorporating the P3M solver in the LH code, it was found that, in order for a self-gravitating hydrodynamic code to be strictly energy conserving, a special ''Consistency Condition'' ought to be satisfied; a new SLH-P3M code was used to demonstrate the effect of including/neglecting the Consistency Condition and also pointed out that most of existing cosmological hydrodynamic codes satisfied that condition.

J.P. Ostriker and N. Gnedin (MIT) further improved the SLH code by including new physical effects that had not been included into numerical simulations before, namely: self-shielding of the intergalactic gas from the radiation background, time-dependent ionization evolution of the intergalactic plasma, detailed non-equilibrium chemistry of molecular hydrogen, and approximate corrections for the finite resolution of a simulation. All these pieces of physics are required in order to simulate the reionization of the pregalactic gas and formation of Lyman-α systems. The work is still in progress: most of the new physics is now incorporated in the code and tested. Large state-of-the-art simulations are planned. The simulations will include 4 million particles and will achieve a dynamical range of $\sim$2000, which is an unprecedented resolution for a hydrodynamic simulation. It is planned to include spatially distributed sources of ionizing radiation, to complete the treatment of radiative transfer.

Gnedin, with J.P. Ostriker and J. Miralda-Escudé (IAS) initiated a project to carry out simple physical modeling of Lyman-alpha systems with the ultimate goal to understand all major physical effects that play roles in formation and evolution of Lyman-alpha systems. The project is currently in progress.

M. Richmond continued to investigate the properties of supernovae, in concert with colleagues at the University of California, Berkeley. Two automatic telescopes at Berkeley's Leuschner Observatory were used to measure precisely the optical light curve of the unusual SN 1994I in M51. This event had a peculiar spectrum, which showed no evidence for hydrogen and little for helium. Its brightness rose very quickly to a peak, then faded equally rapidly, suggesting that its envelope contained little mass; this, in turn, suggests that its progenitor may have been stripped of its outer layers by a companion, or by a very strong stellar wind.

The group also searched through archival images from the Hubble Space Telescope to find high-resolution pictures of the sites of historical supernovae. Of ten candidate sites, most interesting was near the center of the galaxy M83, home of SN 1968L. Multicolor photometry of several star clusters near the location of SN 1968L showed that their stars must be young, less than 7 million years old. If the supernova's progenitor was born at the same time as the clusters, models of stellar evolution predict its mass to have been greater than 25 solar masses, larger than expected for the progenitor of a ''classical'' Type II supernova.

M. Strauss continued his work on observations of the large-scale distribution of galaxies, and statistical and theoretical analyses thereof. In collaboration with B. Santiago and O. Lahav (Cambridge), M. Davis (U.C. Berkeley), A. Dressler (Carnegie), and J. Huchra (Harvard), a redshift survey of the brightest 8600 galaxies in the sky at high Galactic latitudes ($|b|>20$) was completed. This is the first deep redshift survey of optically selected galaxies performed over most of the celestial sphere. Techniques were developed for deriving the galaxy density field from these data correctly accounting for Galactic extinction and the different selection of each of the three galaxy catalogs making up the survey. The luminosity and diameter functions of galaxies are derived; although these quantities are biased by magnitude errors in the catalog, the density field is surprisingly insensitive to magnitude errors.

In collaboration with T. Crawford (Colorado), J. Marr (Union), and B. Partridge (Haverford), Strauss carried out a VLA study at 6 and 20 cm of a sample of 40 ultraluminous IRAS galaxies. The radio morphologies of these objects were found to vary widely, from very compact unresolved sources, to resolved disks, to jet-like linear sources. Nevertheless, the strong correlation observed between the far-infared and radio luminosities of these sources at lower luminosities appears to continue up through the very highest luminosities, arguing that they share a common energy source, namely star formation.

In collaboration with A. Szomoru (Groningen), J. van Gorkom (Columbia) and M. Gregg (LLNL), Strauss carried out a VLA HI study of galaxies in the Bootes Void and in more normal environments. The HI properties of these galaxies (especially HI mass and number of close companions) were found to be surprisingly insensitive to the large-scale (30 Mpc) environment, arguing that galaxy properties are much more determined by their environs on scales of roughly 1 Mpc.

J. Kepner (graduate student), F. Summers, and M. Strauss, derived an extension of the Cosmic Virial Theorem of Peebles which relates the small-scale velocity dispersion of galaxies to their correlations. They show that a similar relation holds for subsets of particles with a common density, which motivates them to suggest a statistic based on redshift surveys that can separate out the density dependence of the velocity dispersion. This statistic may be a useful discriminant between models when the Sloan Digital Sky Survey data become available.

Strauss completed a review of redshift surveys, with special emphasis on developments of the last few years, to be published in the proceedings of a winter school held in Jerusalem in January.

G.R. Knapp and M.P. Rupen (NRAO) completed a survey of elliptical galaxies in the CO(2-1) line using the Caltech Submillimeter Observatory (CSO). Dense cold molecular gas has now been detected in several tens of elliptical galaxies. The overall detection rate is 45%, and the molecular gas correlates well with interstellar dust, seen via its emission at wavelengths $\lambda \geqslant 60\mu$m. The molecular gas content of elliptical galaxies is completely uncorrelated with their luminosity or color. The dense molecular gas appears to be confined to the inner regions of the galaxies (within 1 or 2 kpc) in most cases. CO absorption is seen against a flat spectrum radio source in four galaxies, and the velocities of the narrow absorption components suggest infall to the galactic centers.

Knapp and Rupen, together with M. Fich (Waterloo), D.A. Harper (Chicago) and C.G. Wynn-Williams (Hawaii) have begun a project to acquire broad- band images between 4 and 200 μ m of a large sample of early type galaxies using ISO, to study the distribution of starlight, circumstellar dust and interstellar dust. First results have been obtained from quick-look ISOCAM and ISOPHOT images at 4.5, 6.75, 15 and 21.1 μm of the S0/E galaxy NGC 3998, which has an HI polar ring and a bright semi-stellar nucleus. Emission from the cool bulge stars is seen at the shorter wavelengths, while the longer wavelength observations show a compact source close to the nucleus of the galaxy which is likely to be several thousand $M_\odot$ of dust of temperature $\sim$ 100 – 200 K, perhaps heated by the radiation from the AGN.

G. Jungman (Syracuse), M. Kamionkowski (Columbia), A. Kosowsky (Harvard), and D.N. Spergel showed that the angular power spectrum of the cosmic microwave background (CMB) contains information on virtually all cosmological parameters of interest, including the geometry of the Universe Ω, the baryon density, the Hubble constant (h), the cosmological constant (Λ), the number of light neutrinos, the ionization history, and the amplitudes and spectral indices of the primordial scalar and tensor perturbation spectra. They reviewed the imprint of each parameter on the CMB. Assuming only that the primordial perturbations were adiabatic, they used a covariance-matrix approach to estimate the precision with which these parameters can be determined by a CMB temperature map as a function of the fraction of sky mapped, the level of pixel noise, and the angular resolution. For example, with no prior information about any of the cosmological parameters, a full-sky CMB map with 0.5° angular resolution and a noise level of 15 μK per pixel can determine Ω, h, and Λ with standard errors of $\pm$ 0.1 or better, and provide determinations of other parameters which are inaccessible with traditional observations. Smaller beam sizes or prior information on some of the other parameters from other observations improve the sensitivity. The dependence on the underlying cosmological model was discussed.

D. Spergel, N. Cornish (Case Western Reserve University) and G. Starkman (CWRU) proposed that we live in a finite negatively curved universe. They showed that this suggestion can help reconcile observations that suggest that the universe is open with the predictions of inflation. They have also shown how future microwave background observations could be used to test this hypothesis.

S. Malhotra, D.N. Spergel and J.E. Rhoads used the near infrared fluxes of local galaxies derived from Cosmic Background Explorer (COBE)/ Diffuse Infrared Background Experiment (DIRBE) J(1.25 μm) K (2.2 μm) & L (3.5 μm) band maps and published Cepheid distances to construct Tully-Fisher diagrams for the nearby galaxies. The measured dispersions in these luminosity-linewidth diagrams are remarkably small: σ_J=0.09 magnitudes, σ_K = 0.13 magnitudes, and σ_L=0.20 magnitudes. These dispersions include contributions from both the intrinsic Tully-Fisher relation scatter and the errors in estimated galaxy distances, fluxes, inclination angles, extinction corrections, and circular speeds. For the J and K bands, Monte Carlo simulations give a 95% confidence interval upper limit on the true scatter in the Tully-Fisher diagram of $\sigma_J \leqslant 0.35$ and $\sigma_K \leqslant 0.45$. The Milky Way's luminosity was determined and the Milky Way placed in the Tully-Fisher diagram by fitting a bar plus exponential disk model to the all-sky DIRBE maps. For ''standard'' values of its size and circular speed (Sun-Galactic center distance R_0 = 8.5kpc and Θ_0 =220km/s), the Milky Way lies within 1.5 σ of the TF relations.

Malhotra, Spergel and Rhoads used the TF relation and the Cepheid distances to nearby bright galaxies to constrain R_0 and Θ_0 : $-\log(R_0/8.5\text{kpc}) + 1.63\log(\Theta_0/220\text{km/s}) = 0.08 \pm 0.03$. Alternatively, if standard values are assigned to the parameters of the Galaxy and the Cepheid zero-point is ignored, the Tully-Fisher relation can be used to determine the Hubble Constant directly: $H_0 = 77 \pm 12$ km/s/Mpc.

They have also tested the Tully-Fisher relation at longer wavelengths, where the emission is dominated by dust. No evidence was found for a Tully-Fisher relation at wavelengths beyond 10μm. The tight correlation seen in the L band suggests that stellar emission dominates over the 3.3 μm PAH emission.

R. Kulsrud, R. Cen, J.P. Ostriker and D. Ryu (Korea) proposed a new origin for galactic magnetic fields. They demonstrated that strong magnetic fields are produced from a zero initial magnetic field during the pregalactic era, when galaxies are first forming. The development of the magnetic fields proceeds in three phases. In the first phase, weak magnetic fields are created by the Biermann battery mechanism, acting in shocked parts of the intergalactic medium where caustics form and intersect. In the second phase, these weak magnetic fields are amplified to strong magnetic fields by the Kolmogoroff turbulence endemic to gravitational structure formation of galaxies. During this second phase, the magnetic fields reach saturation with the turbulent power, but they are coherent only on the scale of the smallest eddy. In the third phase, the magnetic field strength increases to equipartition with the turbulent energy, and the coherence length of the magnetic fields increases to the scale of the largest turbulent eddy, comparable to the scale of the entire galaxy. The resulting magnetic field represents a galactic magnetic field of primordial origin. No further dynamo action is necessary, after the galaxy forms, to explain the origin of magnetic fields. However, the magnetic field may be altered by dynamo action once the galaxy and the galactic disk have formed.

The first phase was demonstrated by direct numerical simulation in which the magnetic field equation is added on to the normal equations for structure formation. It was shown that the vorticity and the cyclotron frequency during this phase should be equal everywhere up to a factor involving the fractional ionization. This remarkable result is confirmed by the simulations

The second phase could not be followed by the numerical simulation because of the large numerical resistivity and viscosity. Its behavior was derived by employing a standard analytic theory for the generation of magnetic energy by turbulence.

The investigation of the third phase is being carried out by a complicated numerical turbulence plasma calculation (the Direct Interaction Approximation). This calculation is being done by B. Chandran (graduate student). It is shown that given a steady input of kinetic energy at large scales, the magnetic energy builds up to equipartition with the kinetic energy on all scales. Thus, the magnetic field resulting from phase three appears to be coherent on the largest scale, the scale of the entire galaxy. Qualitative physical arguments seem to bear this out.

Future calculations will investigate the buildup of magnetic energy when the input of kinetic energy is not steady in time. This numerical calculation is also important from the point of view of basic plasma physics. It demonstrates steady state power spectra for MHD turbulence, and explores technical points such as correlation times in MHD turbulence and the effects of kinetic energy sources.

A. Ulmer (graduate student) showed that the two-point correlation function, ξ, of the Lyman-α forest is found to be large, $\xi = 1.8^{+1.6}_{-1.2}$, $>90\%$ confidence level, on the scale of 250-500 km/s for a sample of absorbers ($0 < z < 1.3$) assembled from HST Key Project Observations. This correlation function is stronger than at high redshift ($z > 1.7$) where $\xi \approx 0.2$ for velocities >250 km/s.

By comparing neutrino fluxes and central temperatures calculated from 1000 detailed numerical solar models, J. N. Bahcall (I.A.S.) and A. Ulmer derived improved scaling laws which show how each of the neutrino fluxes depends upon the central temperature (flux $\propto T^m$); they also estimated uncertainties for the scaling exponents. With the aid of a one-zone model of the sun, Bahcall and Ulmer derived analytical expressions for the temperature-exponents of the neutrino fluxes. For the most important neutrino fluxes, the exponents calculated analytically agreed to 20% or better with the exponents extracted from the detailed numerical models. The one-zone model provides a physical understanding of the temperature dependence of the neutrino fluxes. For the pp neutrino flux, the one-zone model explains the (initially-surprising) dependence of the flux upon a negative power of the temperature and suggests a new functional dependence. This new function makes explicit the strong anti-correlation between the ^{7}Be and pp neutrino fluxes. The one-zone model also predicts successfully the average correlation between other neutrino fluxes, but cannot predict the appreciable scatter in a $\Delta\phi_i/\phi_i$ versus $\Delta\phi_j/\phi_j$ correlation diagram.

E.L. Turner, W.N. Colley (graduate student) and J.A. Tyson (Bell Labs) obtained a unique reconstruction of the image of a high-redshift galaxy responsible for multiple long arcs in the $z = 0.4$ cluster 0024+16 by inverse lensing calculations. Deep B and I band imaging with the *Hubble Space Telescope* allowed high resolution of the arcs due to strong gravitational lensing of the background source. Each of the five strongly lensed images of the source yielded the same reconstructed source image, exhibiting a beaded, ringlike morphology. The U luminosity of the ring alone is equivalent to that of a normal bright galaxy, and it is tempting to conclude that this is a galaxy in formation.

Turner and Y. Wang (Fermilab) note that interferometric gravitational wave detectors may someday measure the frequency sweep of a binary neutron star inspiral (characterized by its chirp mass) to high accuracy. The observed chirp mass is the intrinsic chirp mass of the binary source multiplied by $(1+z)$, where z is the source redshift. Assuming a non-zero cosmological constant, the expected redshift distribution of observed events for an advanced LIGO style detector was computed. This redshift distribution has a robust and sizable dependence on the cosmological constant.

Turner, D.J. Eisenstein and A. Loeb (CfA) propose a new method to measure the mass of large-scale filaments found in galaxy redshift surveys. The method is based on the fact that the mass per unit length of isothermal filaments depends only on the transverse velocity dispersion. Filaments that lie transverse to the line of sight may therefore have their masses measured from their thickness in redshift space. Tests of the method on filaments found in N-body simulations show that it is accurate to about 35%, and a preliminary application of the technique to a selected region of the Perseus-Pisces supercluster gives a mass-to-light ratio of 450h in solar units to within a factor of two. This method allows mass-to-light ratio determinations on mass scales up to 10 times larger than that of individual galaxy clusters and could thereby yield new information on the large scale behavior of dark matter.

Turner, A. Stebbins and Y. Wang (Fermilab) have investigated the gravitational lensing of gravitational waves from merging neutron star binaries. They find that the distribution of observed event redshifts (or, equivalently, of observed chirp masses) will have a sharp cut-off in the absence of lensing effects for an advanced LIGO style gravitational wave detector. However, a low amplitude tail extending to higher redshifts (chirp masses) is expected due to gravitational microlensing events. An advanced system might see a few such events per year if compact objects comprised close to 10% of the critical cosmological density.

2.2 Stellar and Galactic Dynamics

With E. Vishniac (Texas) and D. Ryu (Korea), J. Goodman has further investigated a tidal instability of accretion disks in close binary systems. The instability, which was originally described by Goodman in 1993, excites a pair of ingoing and outgoing short-wavelength internal waves at the expense of the orbital energy and angular momentum of the accretion disk. It is a three-dimensional mechanism, which is perhaps why it escaped previous attention, and the growth rate can be comparable to the orbital frequency of the binary. The restoring forces that support the waves are a combination of epicyclic and buoyancy effects — that is, a stable radial stratification of angular momentum and a stable vertical stratification of entropy. The tide destabilizes the waves parametrically. Since Goodman's original publication, the instability has been studied under different approximations by other authors, including Vishniac and Zhang. All of these works computed a local growth rate, which turns out to be a strongly increasing function of radius within the disk, but none decided how the local rate should be averaged to obtain the global rate. Lubow, Pringle, and Kerswell (1993, henceforth LPK) suggested that the local rate had been overestimated by an order of magnitude, but that was shown by Vishniac and Zhang to be an artifact of one of LPK's simplifying approximations. LPK also suggested that the instability would be suppressed by imperfect reflection of the waves at radial boundaries. The recent paper by Ryu, Goodman, and Vishniac shows, first, that the local instability is independent of radial boundaries; and secondly, that the global growth rate is approximately the maximum local growth rate. This wave instability may importantly influence the accretion rate, the truncation of the disk at its outer radius, and the return of angular momentum from the disk to the mass-shedding companion star.

2.3 Stellar Astronomy and the Solar System

G.R. Knapp reviewed observations of the structure of circumstellar dust shells around AGB stars. The photospheres of several red giant stars have recently been found to be non-circularly symmetric, and the asymmetries are aligned with large-scale asymmetries in the circumstellar envelopes. These asymmetries, and those in the subsequent evolutionary stage, planetary nebulae, may be the result of asymmetries in the shapes of the stars themselves.

Knapp and J.E. Gunn, in collaboration with P.F. Bowers (U.S. Naval Observatory) and J. Vasquez Poritz (Cornell undergraduate) analyzed sensitive short-wavelength VLA observations of six globular clusters. Several new candidate low-mass x-ray binary stars were identified by detection of radio point source emission at the positions of cluster x-ray sources. No new planetary nebula candidates were found. The observations also set limits of typically $\lesssim 0.1 M_\odot$ on diffuse ionized gas in the centers of the clusters.

Knapp and A. Jorissen (Brussels), with K. Young (Caltech) detected a very fast ($\geqslant$200kms $^{-1}$) molecular wind from the carbon star V Hya using the CSO. Comparison with other objects showing this phenomenon shows that such winds may signal the onset of planetary nebula formation.

W.N. Colley (graduate student) and J.R. Gott III studied the naked-eye observability of microlensing events for both known stars and possible massive compact halo objects (MACHOs). They found that if both the dark matter disk and halo are composed of MACHOs in the Jupiter-mass range, microlensing events of naked-eye stars, undergoing at least 1 magnitude of magnification, occur at the rate of 1 per 2400 yr., and have durations of from hours to days; they thus surmise that the chance of at least one event occurring in the era of recorded history (the last 5000 yrs.) would be $\sim 1 - e^{-2.1} \sim 88\%$. For magnification by known stars, events are expected at the rate of 1 per 40,000 yr., so we should not be surprised not to have witnessed an event in the last 5000 yr. However, in the last 200,000 yr., while humans have inhabited the Earth, we expect of order five events, and thus a 99% chance that at least one observable event has occurred.

J.R. Gott has continued to investigate the implications of the Copernican Principle for our future prospects. If our location is not special among intelligent observers, the total longevity of our species is predicted to be similar in order of magnitude to that observed for other mammal and hominid species. This study points out how Copernican estimates are identical to those obtained with an appropriate Vague Bayesian Prior. This is no accident – if the Vague Bayesian Prior is chosen correctly then all intelligent observers should be able to use it and then the Copernican results should be obtained.

2.4 Galactic Astronomy and Interstellar Matter

B. Paczynski and his associates worked mostly on a major observing program aimed at detecting gravitational microlensing in our Galaxy (the Optical Gravitational Lensing Experiment - OGLE), and various projects that arose serendipitously from the OGLE data. The most important new result was the discovery of a number of detached eclipsing binaries in the globular cluster Omega Centauri, and the presentation of theoretical reasons for those systems to be excellent distance and age indicators. It is expected that within the next few years, studies of detached eclipsing binaries will provide an accurate distance scale within the Local Group of Galaxies, and reliable ages for the globular clusters.

Paczynski wrote a review article about the current status of microlensing searches towards the galactic bulge and the Large Magellanic Cloud, and the prospects for future developments.

H-S. Zhao (MPI/Munich), M. Rich (Columbia) and Spergel constructed a consistent microlensing model of the Galactic bar. The predicted event rates and event durations are consistent with the 55 events reported recently by the MACHO and OGLE collaborations. Most of the events are due to lensing by stars in the near end of the bar. Lens mass functions with about 30-50% of lens mass as brown dwarfs are rejected at 2-6σ levels. To make the standard model useful for other workers, the bar's optical depth and average event duration (scaled to $1M_\odot$ lenses) were tabulated on a grid of Galactic coordinates. The distance and the proper motions of the lens and the source were derived from a consistent dynamical model of the stellar bar, which was originally built to fit data on the stellar light and stellar/gas kinematics of the bar. Several alternative models were explored and the standard model was found to best match observations.

B.T. Draine has continued to work on theoretical astrophysics of the interstellar medium with particular attention to (1) dust grains; (2) photodissociation fronts; and (3) shock waves.

Draine and J. Weingartner (graduate student) are studying the effects of radiative torques exerted on irregular dust grains when they are illuminated by starlight. The theory underlying calculation of these torques was developed, and torques were calculated for examples of irregular grains using a modified version of the DDSCAT code for calculation of scattering and absorption of light using the discrete dipole approximation. Radiative torques exerted on grains by the interstellar radiation field can result in spinup of grains to superthermal rotation rates. Even isotropic starlight can produce superthermal rotation, but modest anisotropies in the radiation field – such as are expected in the interstellar medium – can be very important. Work now in progress investigates the role which anisotropic starlight may play in the process of alignment of dust grains with the magnetic field.

Draine reviewed the electromagnetic properties of grains important for the physics of dust grain alignment. In particular, the frequency-dependence of the imaginary part of the magnetic susceptibility was examined for paramagnetic, superparamagnetic, and ferromagnetic materials. Since dust grains can in some cases be spinning very rapidly, it is important to understand the frequency-dependence of the magnetic dissipation.

Draine, in collaboration with F. Bertoldi (MPI, Garching), continued to work on the theory of time-dependent photodissociation fronts associated with ionization fronts. The theory of coupled ionization-dissociation fronts was developed to determine under what circumstances the dissociation fronts will not be well-approximated by ''classical'' models of stationary, steady-state photodissociation fronts.

The theory of stationary photodissociation fronts was investigated by Draine and Bertoldi. It was shown that overlap of the ultraviolet absorption lines of H_2 (neglected in much previous work) can often be important. New approximations were developed for the treatment of self-shielding when line overlap becomes important, and photodissociation front models including these effects were computed. The models were applied to the bright photodissociation region in NGC 2023, for which there are now observations of H_2 fluorescent emission in both the K band and the far-red. It is shown that the photodissociation region in NGC 2023 must be considerably denser and warmer than previously believed in order to reproduce the observed H_2 emission spectrum.

Grain destruction in shock waves is important because of its role in the evolution of the interstellar grain population and because it can alter the gas-phase abundance of atoms, ions, and molecules in a shock wave. The destruction of grains in interstellar shock waves was reviewed by Draine for the Manchester conference ''Shocks in Astrophysics.''

E. Jenkins collaborated with G. Wallerstein (U. Washington), A. Vanture (U. Washington) and G. Fuller (U.C., San Diego) in a search for an enhancement of some r-process elements in the interstellar material within the Vela supernova remnant. The GHRS on HST was used to observe wavelength regions centered on the absorption lines of Ge II, Kr I, Yb II, Os II and Hg I in the uv spectra of 5 stars whose locations were within about 1 degree of the position of the Vela pulsar. The only features that were detected were those of Ge II. The column density of Ge II and upper limits for other species indicated that the abundances of these elements were consistent with the usual cosmic abundances, with no measurable enrichment arising from gas ejected by the supernova.

In another observing program with the GHRS on HST, Jenkins, Wallerstein and Vanture compared interstellar absorption lines appearing in the uv spectra of two components of the visual binary HD72127A,B behind the Vela supernova remnant. The objective of their study was to observe some important uv transitions to obtain a better understanding of differences in the interstellar material within the remnant over a length scale as small as 0.013 pc. Previous ground-based observations of the Ca II lines showed that there were differences in the interstellar features for these two stars. The fine-structure excitation of C I indicates that some of the material in front of the stars is at an elevated pressure $[\log(p/k) > 5.5]$ and thus must have been shocked and compressed by the supernova blast wave. Lines of Ge II and P II are seen in star A but seem to be significantly weaker in star B, while the weak lines of Mg II appear to be identical in both stars. The data recorded in this program will also be useful for future studies that will search for changes in the features with time.

Jenkins and Wallerstein measured the abundances of various elements in the interstellar gas in front of 3 stars in the galactic halo, again using the GHRS. It is known from previous investigations that certain elements show much less depletion in the halo than in the disk. By comparing the results for the halo stars with shocked gas in the Vela remnant (in front of HD72089), Jenkins and Wallerstein found that the pattern of depletions from one element to another were consistent with that of reduced depletions caused by the destruction of dust grains. These results seem to rule out the proposition that such changes are caused principally by the injection of iron-peak elements by Type Ia supernovae in the halo. The lack of a significant increase in the concentrations of these elements is probably due to the exchange of matter between the halo and disk of our galaxy.

A. Lazarian has continued to work on developing the theory of grain alignment. For paramagnetic alignment of grains rotating under the influence of torques arising from H_2 formation (Purcell alignment), the major process which limits the life-time of catalytic sites of H_2 formation was shown to be oxygen poisoning, rather than the customarily accepted grain resurfacing. Grains smaller than a calculated critical size were shown to have short-lived spin-up, and the preferential alignment of large grains was established. Lazarian also elaborated on the way photodesorption enhances the alignment.

Lazarian studied paramagnetic alignment of thermally rotating oblate grains (Davis-Greenstein alignment). A perturbative approach to solving the corresponding Fokker-Planck equation was used, and analytical solutions were obtained. The accuracy of these results was confirmed by independent numerical simulations. Working on the alignment of thermally rotating grains Lazarian showed that thermal fluctuations within the grain material limit the degree of alignment of the grain angular momentum with the grain principal axis of maximal inertia. This effect was shown to decrease the Rayleigh reduction factor for the Gold and Davis-Greenstein alignments.

Lazarian analyzed the mechanical alignment of grains rotating suprathermally, i.e,. with kinetic energy substantially exceeding the energy of Brownian rotation and proposed two new mechanisms of alignment. So-called ‘‘crossover alignment’’ happens due to angular momentum delivered to the grain by a gaseous flow during ‘‘crossovers,’’ the short intervals between successive spin-ups. Although crossovers are short, grains are susceptible to alignment because their angular momenta are small during these intervals. ‘‘Cross-section alignment’’ happens due to variation of the grain-gas cross-section for different angles of grain orientation. This difference influences the time back to crossover. Analytical expressions for the measure of alignment when both mechanisms were in action were derived. This study indicates that mechanical alignment can be more widely spread than it is usually believed. In collaboration with M. Efroimsky (Tufts University), A. Lazarian elaborated the theory of the cross-sectional alignment for oblate grains, and showed that grain helicity is an important factor which must be accounted for.

Lazarian, in collaboration with P. Gerakines (RPI) and D. Whittet (RPI), studied grain alignment in the Taurus dark cloud. The variations of the polarization efficiency (p/A) for this cloud were shown to obey a power law $p/A \sim A^{-0.56}$. The effects of small-scale magnetic field structure, coupling of the dust-gas temperature and depletion of the atomic hydrogen with optical depth were examined.

Together with A. Chrysostomou, J. Hough, D. Aitken (Hertfortshire), D. Whittet (RPI) and P. Roche (Oxford) A. Lazarian has studied interstellar polarization arising from CO mantled grains. The polarization in both broad and narrow CO components was detected and the consequences for grain alignment theory were discussed.

A. Lazarian and E. Vishniac (UT, Austin) have studied the structure of magnetic field embedded in a turbulent plasma and applied the results to the ISM. They showed that the field can form isolated flux tubes that are confined both by the pressure of the external gas and by shocks in the surrounding media. This fibralization alters the conventional dynamo theory and invalidates a number of anti-dynamo arguments.

A. Howard (recent Ph.D. student) and Kulsrud continued their research on the evolution of a primordial magnetic field. They showed that the results of their model produced a magnetic field that is not subject to the main objections advanced against a primordial magnetic field. The wind up of the magnetic field by galactic rotation leads to a tightly wound azimuthal field, but this field can be shown to be in agreement with observations. Compression in the spiral density wave makes the magnetic field nearly parallel to the spiral arms in the region of the arms, so that observations of such a field in other galaxies would detect a magnetic field that would appear to trace out the spiral arms. The field would be azimuthal in between the arms. The rapid reversal of the field on the scale of about one hundred parsecs need not average out when the magnetic field is observed at any reasonable resolution. Further, because of its topology the magnetic field can not be expelled from the galactic disk in a finite time.

D. Uzdensky (graduate student), R. Kulsrud and M. Yamada (PPPL), developed a general theory of magnetic reconnection at large magnetic Reynold’s numbers. They showed that any magnetic reconnection problem breaks naturally into a global magnetostatic problem, which can be solved independently of the magnetic reconnection process, and a local problem consisting of the determination of the physics of the magnetic reconnection in the very thin resistivity layer. The global problem connects the general boundary conditions (far away), to the reconnection. In the bulk of the region outside of the reconnection layer motions are very small, and resistivity is negligible. The parameters which uniquely determine the solution of the global problem, are determined by demanding that the entropy on the freshly reconnected surface satisfy total energy conservation. This enables one to properly take into account the conversion of magnetic energy into kinetic and thermal energy. The change of topology of the magnetic lines during reconnection must also be properly taken into account. The solution of the global problem uniquely determines the position of the reconnection layer and also most of the conditions outside of the layer. Using these conditions it is believed possible to solve for the physics of the reconnection in the layer depending on the relevant physical properties of the plasma. This breakup leads to a considerable simplification of the reconnection problem and should make possible a nearly general solution of the complete reconnection problem in the limit in which the magnetic Reynold’s number is large compared to one. The ambiguity in the solution depends only on whether the plasma in the reconnection layer acts as a resistive fluid or a collisionless fluid and whether there are anomalous resistivity processes present in the layer. This ambiguity, in general, does not affect the global solution.

B. Chandran (graduate student) completed his study extending the quasilinear theory for the amplification of small scale magnetic fields by turbulence, taking into account the effects of realistic velocity correlation times. A new type of numerical simulation was used to evolve the magnetic field at a point moving with the flow in a random velocity field. The ideas of Kraichnan were used to model the random velocity field. The numerical simulations indicated that the quasilinear theory overestimates the growth rate of the magnetic energy by a factor of about 2. This result is important, because the quasilinear theory is not applicable to Kolmogoroff turbulence, and thus might have been off by orders of magnitude, leading to spurious conclusions about the origin of cosmic fields. An analytic theory based on the work of Van Kampen was also used to corroborate and explain the results of the simulations.

In a separate project, Chandran investigated four stages in the turbulent amplification of small scale magnetic fields in the early Galaxy assuming the Galaxy is born with a very weak magnetic field. In the first stage, the magnetic field is dynamically unimportant, and magnetic energy builds up very rapidly on scales much smaller than the smallest turbulent eddies. In the second stage, this small scale magnetic field is strong enough to influence the smallest turbulent eddies. The small scale field acts like a network of tangled rubber bands, making the plasma elastic to large scale motions. This leads to the conversion of some of the hydrodynamic modes into elastic shear waves. In the third stage, a new type of damping of magnetic fields places a ceiling on the energy of the very small scale magnetic field, allowing fields to build up only on the scales of the turbulent eddies. This new type of damping is analogous to ambipolar damping, only ions and neutrals move together to straighten out field lines. In the fourth stage, the magnetic field becomes strong on the scales of the velocity eddies. Strong MHD turbulence develops, and is treated using a numerical integration of the direct interaction approximation (DIA) equations. It is shown that the magnetic energy builds up to equipartition with the turbulent energy on all scales.

The source of the highly ionized interstellar atoms has been considered by Spitzer, based on a comparison of the column density ratio $N(C^{+3})$ / $N(O^{+5})$ between the Galactic halo and disks. The C^{+3} observations were mostly obtained with the Goddard High-Resolution Spectrograph on HST, partly by Fitzpatrick & Spitzer and partly by Huang, Songaila, Cowie and Jenkins. The O^{+5} observations were obtained by Jenkins with *Copernicus*. Toward six disk stars this ratio averages 0.15, toward five halo stars, 0.9. Individual values scatter about these means by about a factor two. The low value toward disk stars agrees with models of conductive heating of a cool gas in contact with a hot one, as in theories of cloud evaporation, stellar winds, and young supernova remnants. The higher ratio toward halo stars is in the general range covered by different theories of downfalling, initially hot gas, as in a Galactic fountain. These data, while limited, tend to confirm theoretical expectations as to the major dynamical processes in the interstellar halo and disk.

E.L. Fitzpatrick and Spitzer have continued their multiyear study of the physical properties of individual interstellar clouds with a detailed examination of the line of sight towards the star HD 215733. This star is located at a distance of $\sim$3000 pc, some 1700 pc below the Galactic plane, in the direction $(l,b) = (85°, -36°)$. Analysis of data from the *Goddard High Resolution Spectrograph* ($\lambda/\delta\lambda \simeq 85000$) and the Kitt Peak Coudé Feed spectrograph ($\lambda/\delta\lambda \simeq 200000$) reveals an exceedingly complex line of sight, with more than 20 individual absorption components identified in the low-ionization species.

The determination of kinetic temperatures T_k and electron densities n_e for the individual components (clouds) is a primary goal of this study. In strong contrast to another halo star (HD 93521), most of the gas seen towards HD 215733 is cold, with temperatures of order 100 K. Five different electron density diagnostics are available, based on collisional excitation equilibrium of C^+ fine structure levels, and ionization equilibrium of C^0/C^+, Mg^0/Mg^+, S^0/S^+, and Ca^+/Ca^{++}. The various ionization equilibrium diagnostics are found to have systematic discrepancies of up to 1 dex, in the sense that the values involving the neutral species tend to be larger than those derived from the Ca^+/Ca^{++} ratio. The values derived from Ca are consistent with the observed C^+ excitation in the cold clouds if the free electrons come primarily from ionization of the metals. The gas pressures P/k implied by this condition are reasonable, in the range 1000–5000 cm^{-3}K. The reason for the discrepancy among the ionization equilibrium diagnostics is not known. Future studies will seek to establish the systematic behavior of these discrepancies.

Analysis of the highly ionized species C^{3+}, Si^{3+}, and N^{4+} towards HD 215733 reveals an additional 7 absorption components, found in one or more of the ''high ions.'' For two of the high ion components, both Si^{3+} and C^{3+} are observed with a ratio of line widths which equals the square-root of the atomic mass ratio, indicating thermal broadening at temperatures of 6×10^5 K and 5×10^4 K. The column density ratios of C^{3+} to Si^{3+} in these two components would require a temperature of about 8×10^4 K in collisional equilibrium. This result appears to give direct observational confirmation that transient phenomena must be assumed if collisional ionization is to explain the high ion data.

Fitzpatrick has analyzed the pattern of interstellar gas-phase abundances of the elements Si, S, Mn, Cr, Fe, and Zn derived for about 30 individual interstellar clouds along the sightlines toward the Galactic disk star HD 68273 and the halo stars HD 93521, HD 149881, and HD 215733. The gas-phase abundance of S relative to H in these clouds appears indistinguishable from the solar value. For the other elements, well-defined upper limits are found in the gas-phase abundances at significantly subsolar values. For Fe, Mn, and Cr (and probably Ti) there are no convincing cases where the relative gas-phase abundances exceed ~ -0.5 dex, i.e., these elements have not been seen in interstellar gas with an abundance greater than about 1/3 solar. For Si the limit is ~ -0.15 dex, and for Zn a constant abundance of -0.13 dex is found from seven clouds along one halo sightline. These subsolar maximum abundances have two possible interpretations: (1) they indicate the presence of an essentially indestructible component of interstellar dust, which contains about 2/3 of the Ti, Mn, Cr, and Fe and about 1/3 of the Si (assuming that the intrinsic interstellar abundances are solar) or (2) they indicate that the true total abundances of these elements are substantially less than in the Sun. The subsolar abundance hypothesis is qualitatively consistent with recent suggestions — based primarily on measurements of O in the ISM and of a number of elements in nearby B-type stars — that the general metallicity of the ISM could be as much as 0.2 dex below that of the Sun. The magnitude of the departure from solar abundances for Fe, Cr, Mn, and Ti is however much greater than has been suggested for other elements and may be difficult to reconcile with the stellar results.

E.L. Turner and Y. Wang (Fermilab) point out that for a given source and gravitational lens pair, there is a thin on-axis tube-like volume behind the lens in which the radiation flux from the source is greatly increased due to gravitational lensing. Any objects (such as dust grains) which pass through such a thin tube will experience strong bursts of radiation, i.e., Extreme Gravitational Lensing Events (EGLE). They study the physics and statistics of EGLE for the case in which finite source size is more important than shear. As an illustration of one of the several possible significant astrophysical effects, they investigate the evaporation of dust grains by EGLE in an idealized globular cluster system.

2.5 Instrumentation and Software

E. Jenkins, P. Zucchino and M. Reale have completed their modifications and testing of the Interstellar Medium Absorption Profile Spectrograph (IMAPS), scheduled to fly on its second ORFEUS-SPAS mission from a Shuttle launch in November 1996. IMAPS is an objective-grating spectrograph that records the spectra of bright stars over the wavelength interval 950-1150A at a resolving power of about 150,000. Approximately 50% of the observing time for IMAPS will be available to guest observers who submitted winning proposals to the US and German space agencies, NASA and DARA.

D. Spergel is part of a Princeton/Goddard collaboration led by C. Bennett (GSFC) to build the MAP satellite. NASA has selected MAP as the next astrophysics MIDEX. It will map the microwave background fluctuations across the entire sky at an angular resolution of better than 20 arcminutes. MAP is scheduled for launch late in the year 2000.

The Sloan Digital Sky Survey effort at Princeton has included both construction of the giant CCD drift-scan camera for the 5 band imaging survey as well as development of the photometric pipeline for automatic processing of the multiband imaging data. J.E. Gunn has for the past three years been primarily concerned with various aspects of the Sloan Digital Sky Survey. He is currently project scientist for the project and as well is the principal investigator responsible for the construction of the large multi-CCD imaging camera for the survey.

The development of the photometric pipeline software for automatic reduction of the imaging data of the Sloan Digital Sky Survey (SDSS) has continued at Princeton by a group consisting of R. Lupton, N. Ellman, M. Richmond, J. Gunn and G. Knapp. Some code has also been written by T. Quinn (U. Washington).

The photometric pipeline's tasks include the selection of stars which will be used to calibrate the flux densities, correction of the data for cosmic rays and CCD defects (such as bad columns), flattening, determination of sky levels, finding objects, combining observations of an object in all five filters, measuring the brightness, position, size and shape of the objects, deblending objects with overlapping images, and extracting from the corrected imaging data the image of each object.

The photometric code has been successfully ported to the hardware platform which will be used to run the survey and has been successfully integrated with the pipelines which provide the photometric and astrometric calibration. Most of the coding is finished (deblending remains to be completed) and the software has been extensively tested using detailed simulations of the sky made by D. Weinberg (Ohio State), M. Doi (University of Tokyo) and B. Yanny (Fermilab). Independent tests have also been carried out of much of the software by N. Yasuda, K. Shimasaku, M. Fukugita and M. Doi (Universities of Tokyo and Kyoto). Integration with the Operational Data Base is well underway. The use of the photometric outputs for spectroscopic target selection has also been evaluated, as has input to the science data base.

Princeton software scientists have also contributed to other parts of the project. Richmond has made extensive contributions to the monitor telescope data reduction pipeline, which reduces the photometric calibration data and passes the results to the photometric pipeline, and to the acquisition and reduction of photometric calibration data. He has also participated in the development of the operational data base. Lupton and Gunn have contributed to the data acquisition software, and Lupton has worked on the operating system and on design of the science data base.

The SDSS hardware comprises several major subsystems, responsibility for which is spread over most of the participating institutions. The current schedule calls for installation of all subsystems on Apache Point in November 1996. It is anticipated that several months subsequently will be required to iron out system problems and to tune the various subsystems for peak performance as a system. The major subsystems are:

Structures and Support Services at APO

This is primarily the responsibility of the APO staff. All the buildings are finished, and all the road work has been done. One major item, for which Princeton is responsible, is the construction of a clean room for servicing the camera.

The Telescope and its Mounting

The telescope system is primarily the responsibility of the University of Washington, with the major subcontract for construction handled by L&F Industries in Los Angeles. Fermilab has considerable responsibility for the control system.

The telescope is on the mountain, assembled and working in a rudimentary way. Since it will not be working in a conventional dome, light and wind protection are afforded by a novel wind baffle. The instrument also has quite complex light baffles to accomodate its very wide field. The drives have been measured, and represent the most accurate system yet achieved on any telescope of any size.

Fermilab has responsibility for the control system and a large number of scientists and engineers are currently working on it intensively. The system is basically straightforward, but the accuracy required in order to meet the goals of the project (and to utilize the superb accuracy of the mechanical components) is not easy to achieve.

The Optics

The University of Washington has contractual responsibility for the optics, which were done by several vendors. The primary, at The University of Arizona Optical Sciences center, was finished in June, and meets specifications except for a slight large-scale warp which can be taken out by small forces built into the mirror mounting system. The secondary, figured by the Mirror Lab of the University of Arizona and tested by a revolutionary new technique for characterizing these classically very difficult-to-test convex mirrors, exceeds specification by nearly a factor of two. The very complex aspheric camera corrector, which forms the substrate for the camera assembly, was delivered by Don Loomis in the early spring and is superbly done, as is the very strongly curved spectroscopic final corrector, done by Tinsley and delivered in July. The common (Gascoigne) corrector is under construction by Contraves and is scheduled for a mid-October delivery.

The Monitor Telescope

The MT is a 0.6m telescope which will work alongside the 2.5 meter in order to provide brightness standards and to characterize the transmission of the atmosphere. It is working, taking data, and in the process of finalization of its software and a final rework to correct some deficiencies in its electronics.

The Spectrographs

The spectrographs are being constructed at Johns Hopkins, and their CCD cameras and electronics at Princeton. Both systems are substantially finished; a working camera has been delivered to JHU, and tested with the Fermilab data acquisition system.

The Camera

Princeton is constructing the CCD survey camera. Final assembly of the instrument is underway. Essentially all of the mechanical parts have been delivered; all of the CCD detectors have been received, tested, characterized, and mounted to their precision holders. The major electronic circuit boards are all finished and have been fully populated and tested. An electronics team consisting of J. Gunn, G. Pauls (Princeton), C. Rockosi (Chicago), M. Sekiguchi (National Observatory, Japan), F. Harris (Naval Observatory), J. Brinkman (APO), and D. Sandford (Chicago) converged in Princeton this summer and substantially finished the very complex electronics system. The mechanical part of the camera is being done by J. Gunn, M. Carr (Princeton), M. Sekiguchi (Japan), with machining assistance by B. Elms (Princeton). Assembling the camera to the tolerances designed has proven to be even more painstaking than originally envisioned. The camera is scheduled for installation at Apache Point in November 1996.

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