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This report covers the period 1 July 1996 — 30 June 1997.

1. PERSONNEL

During the reporting year, the Research Staff was joined by Željko Ivezić (from the University of Kentucky), Alexandre Refregier (from Columbia University), Todd Tripp (from University of Wisconsin), and Michael Vogeley (Hubble Fellowship Program, Space Telescope Science Institute). Professor Lyman Spitzer, Jr. passed away on 31st March and Martin Schwarzschild passed away on 10th April.

Honors were conferred upon several members of the department. Neta Bahcall was elected to the National Academy of Sciences. Bohdan Paczynski received the Henry Draper Award from the National Academy of Sciences. Michael Strauss received the Newton Lacy Pierce Prize in Astronomy. Martin Schwarzschild was posthumously awarded the 1997 National Medal of Science.

Associate Professors Jeremy Goodman and David Spergel were both promoted to full Professor. Bruce T. Draine was appointed chair of the Department of Astrophysical Sciences and director of Princeton University Observatory.

Visitors staying over one month included: Changbom Park (Seoul National University), Michael Rupen (National Radio Astronomy Observatory), Kandau Subramanian (Tata Institute of Fundamental Research), and HonSheng Zhao (Leiden Observatory).

The Spitzer Lecturer in the spring was John P. Huchra, Harvard College, Center for Astrophysics who presented a series of lectures on survey-related work, including redshift surveys, ROSAT, and 2MASS.

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 (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 ~ 600 km s^{-1}. The root-mean-square cluster peculiar velocity is 293 ± 28 km 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 consistent with a low mass-density ($\Omega \sim 0.3$) CDM model and 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 ± 28 km s^{-1} further supports the low-density CDM model.

N. Bahcall, X. Fan (graduate student), and R. Cen showed that the evolution of the number density of rich clusters of galaxies breaks the degeneracy between Ω (the mass density ratio of the universe) and σ_8 (the normalization of the power spectrum), $\sigma_8 \Omega^{0.5} \simeq 0.5$, that follows from the observed present-day abundance of rich clusters. They showed that the evolution of high-mass (Coma-like) clusters is strong in $\Omega = 1$, low-σ_8 models (such as the standard based CDM model with $\sigma_8 \simeq 0.5$), where the number density of clusters decreases by a factor of $\sim 10^3$ from $z = 0$ to $z \simeq 0.5$; the same clusters show only mild evolution in low-Ω, high-ω_8 models, where the decrease is a factor of ~ 10. This diagnostic provides a most powerful constraint on Ω. Using observations of clusters to $z \simeq 0.5 - 1$, they found only mild evolution in the observed cluster abundance. They determined $\Omega = 0.3 \pm 0.1$ and $\sigma_8 = 0.85 \pm 0.15$ (for $\Lambda = 0$ models; for $\Omega + \Lambda = 1$ models, $\Omega = 0.34 \pm 0.13$). These results imply, if confirmed by future surveys, that we live in a low-density, low-bias universe.

N. Bahcall reviewed some of the unsolved problems in the study of large-scale structure of the universe and summarized goals for their resolution. She reviewed the current status and future use of large-scale structure investigations from multi-wavelength sky surveys, including the Sloan Digital Sky Survey, and their impact on cosmology. Bahcall also reviewed the topics of clusters of galaxies, superclusters, and voids as well as dark-matter in the universe, including both observations as well as cosmological implications.

J.R. Gott, R. Cen, 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) 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 ''spirals'') 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 and J.P. Ostriker, in collaboration with T. Padmanabhan and F.J. Summers, studied the nonlinear clustering of dark matter particles in an expanding universe using

N-body simulations. They investigate nonlinear clustering for 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 $\Omega_{CDM}=0.4$, $\Omega_{\Lambda}=0.6$; and $n=-1$ 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 $\Omega<1$ 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. They present simple theoretical arguments for these conclusions.

R. Cen and J.P. Ostriker, in collaboration with J. Wambsganss, described in detail a new method to trace light rays through an essentially three dimensional mass distribution up to high redshift. As an example, they applied this method to a standard cold dark matter universe. They obtained a variety of results, 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 functions of quasar redshift. They found effects 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. One can thus study the weak coherent shear fields produced by lensing of large-scale structure 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. The 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 and J.P. Ostriker, in collaboration with J. Wambsganss and G. Xu, examined effects of the weak gravitational lensing by large-scale structure on the determination of the cosmological deceleration parameter q_0. They find that the lensing induced dispersions on truly standard candles are 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 errorbars 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 R.A. Simcoe (undergraduate), performed a detailed analysis of the Lyα clouds produced by cosmological hydrodynamic simulations of a spatially flat cold dark matter universe with a non-zero cosmological constant. They found a very wide variety of structures, ranging from roundish high-density regions with $N_{HI}>10^{16}$ 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 this 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 show 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 conjecture that high column density Lyα clouds ($N_{HI}>10^{16}$ cm^{-2}) may be progenitors of the lower redshift faint blue galaxies, 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 in the Babul & Rees proposal.

R. Cen and J.P. Ostriker, in collaboration with J. Miralda-Escudé (University of Pennsylvania), 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 $\Omega=0.4$. The intergalactic, photoionized gas is predicted to collapse into sheet-like and filamentary structures which give rise to absorption lines having characteristics similar to the observed Lyα forest. A typical filament is $\sim1h^{-1}$ Mpc long with thickness $\sim50-100h^{-1}$ kpc (in proper units), and baryonic mass $\sim10^{10}h^{-1}M_{\odot}$. The cell size is $(2.5,9)h^{-1}$kpc in the two simulations, with true resolution perhaps a factor of 2.5 worse than this. The gas temperature is in the range 10^4 - 10^5

K, increasing with time as structures with larger velocities collapse gravitationally.

The predicted distributions of column densities, b-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 intensity between $z=2$ and $z=4$. A new method of identifying lines as contiguous regions in the spectrum below a fixed flux threshold is suggested to analyze the absorption lines, 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. They predict a correlation length of $\sim 80h^{-1}$ kpc perpendicular to the line of sight 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 low densities and large volume- filling factors. If the background intensity J_{hi} is at least that predicted from the observed quasars, Ω_b needs to be as high as $\sim 0.025h^{-2}$; the model also predicts that most of the 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. Kulsrud, R. Cen and J.P. Ostriker, in collaboration with D. Ryu, demonstrated that strong magnetic fields are produced from a zero initial magnetic field during the pregalactic era, when the galaxy is first forming. Their development proceeds in three phases. In the first phase, weak magnetic fields are created by the Biermann battery mechanism. Results from a numerical simulation make it appear likely that during the second phase homogenous isotropic Kolmogoroff turbulence develops associated with gravitational structure formation of galaxies. Assuming that this turbulence is real then these weak magnetic fields will be amplified to strong magnetic fields by this Kolmogoroff turbulence. 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. During the third phase, which follows this saturation, it is expected that the magnetic field strength will increase to equipartition with the turbulent energy and the coherence length of the magnetic fields will increase to the scale of the largest turbulent eddy, comparable to the scale of the entire galaxy. No further dynamo action after the galaxy forms is necessary to explain the origin of magnetic fields. However, the magnetic field will certainly be altered by dynamo action once the galaxy and the galactic disk have formed.

Cen studied the effects of projection on various observables of clusters of galaxies at redshift near zero, including cluster richness, velocity dispersion, X-ray luminosity, three total mass estimates (velocity-based, temperature-based and gravitational lensing derived), gas fraction and substructure, utilizing a large simulation of a realistic cosmological model (a cold dark matter model with the following parameters: $H_0=65$km/s/Mpc, $\Omega_0=0.4$, $\Lambda_0=0.6$, $\sigma_8=0.79$). Unlike previous studies focusing on the Abell clusters, it was conservatively assumed that both optical and X-ray observations can determine the source (galaxy or hot X-ray gas) positions along the line of sight as well as in the sky plane accurately; hence we only include sources inside the velocity space defined by the cluster as possible contamination sources. Projection effects are found to be important for some quantities but insignificant for others.

It was shown that, on average, the gas to total mass ratio in clusters appears to be 30-40% higher than its corresponding global ratio. Independent of its mean value,the broadness of the observed distribution of gas to total mass ratio is adequately accounted for by projection effects, alleviating the need to invoke other non gravitational physical processes. While the moderate boost in the ratio narrows the gap, it is still not quite sufficient to reconcile the standard nucleosynthesis value of $\Omega_b=0.0125(H_0/100)^{-2}$ (Walker, *et al.*, 1991) and $\Omega_0=1$ with the observed gas to mass ratio value in clusters of galaxies, $0.05(H_0/100)^{-3/2}$, for any plausible value of H_0. However, it is worth noting that real observations of X-ray clusters, especially X-ray imaging observations, may be subject to more projection contaminations than we allow for in our analysis. In contrast, the X-ray luminosity of a cluster within a radius $\leqslant 1.0h^{-1}$Mpc is hardly altered by projection, rendering the cluster X-ray luminosity function a very useful and simple diagnostic for comparing observations with theoretical predictions.

Rich cluster masses $[M(<1.0h^{-1}Mpc)\geqslant 3\times 10^{14}h^{-1}M_\odot]$ derived from X-ray temperatures or galaxy velocity dispersions underestimate, on average, the true cluster masses by about 20%, with the former displaying a smaller scatter, thus providing a better means for cluster mass determination. The gravitational lensing reconstructed (assuming an ideal inversion) mass overestimates the true mass by only 5-10% but displays a dispersion significantly larger than that of the X-ray determined mass.

Projection inflates substructure measurements in galaxy maps, but affects X-ray maps much less. Most clusters ($\geqslant$90%) in this model universe do not contain significant intrinsic substructure on scales $\geqslant 50h^{-1}$kpc at $R_{proj}\leqslant 1h^{-1}$Mpc without projection effects, whereas more than $\sim$50% of the same clusters would be ''observed'' to show statistically significant substructure as measured by the Dressler-Shectman Δ statistic. The fact that a comparable fraction ($\sim$50%) of real observed clusters show substructure measured in the same way implies that most of the substructure observed in real clusters of galaxies may be due to projection.

Finally, it was pointed out that it is often very difficult to correctly interpret complex structures seen in galaxy and X-ray maps of clusters, which frequently display illusory configurations due to projection. The best way to compare predictions of a cosmological model with the cluster observations is to subject clusters in a simulated universe to exactly the same observational biases and uncertainties, including projection and other instrumental limitations, and to compare the ''observed'' simulated clusters with real ones.

Cen investigated the high end of the Lyα optical depth distribution of a quasar spectrum. Based on the flux distribution (Miralda-Escudé, *et al.*, 1996), a simple yet seemingly cosmological model-differentiating statistic, Δ_{τ_0} — the cumulative probability of a quasar spectrum with Lyα optical depth greater than a high value τ_0 — was emphasized. It was shown that two different models — the cold dark matter model with a cosmological constant and the mixed hot and cold dark matter model, both normalized to COBE and local galaxy cluster abundance — yield quite different values of Δ_{τ_0}. Moreover, it was argued that Δ_{τ_0} may be fairly robust to compute theoretically. Furthermore, Δ_{τ_0} can be obtained sufficiently accurately from currently available observed quasar spectra for $\tau_0 \sim 3.0-4.0$, when observational noise is properly taken into account. Analyses of observations of quasar Lyα absorption spectra over a range of redshift may be able to constrain the redshift evolution of the amplitude of the density fluctuations on small-to-intermediate scales, therefore providing an independent constraint on Ω_0, $\Omega_{0,HDM}$ and Λ_0.

Cen studied the cluster-cluster two-point correlation functions in topological defect models. Gaussian cosmological models, typified by the inflationary cold dark matter models, and non-Gaussian topological defect based cosmological models, such as the texture-seeded model, differ in the origin of large-scale cosmic structures. Textures initially are randomly distributed on scales larger than their size, in sharp contrast to the initial high-density peaks in the Gaussian models, which are already strongly clustered before any gravitational evolution has occurred. One thus expects that the resultant correlation of large cosmic objects such as clusters of galaxies in the texture model should be significantly weaker than its Gaussian counterpart.

An $\Omega_0=1$ biased $b=2$ (as required by cluster abundance observations) texture model (or any random seed model) predicts a two-point correlation length of $\leq 6.0h^{-1}$Mpc for rich clusters, independent of richness. On the other hand, the observed correlation length for rich clusters is $\geq 10.0h^{-1}$Mpc at an approximately 2σ confidence level. It thus appears that the global texture cosmological model or any random seed cosmological models are ruled out at a very high confidence $(>3\sigma)$.

Cen and Ostriker, in collaboration with S. Phelps (physics graduate student) and J. Miralda-Escudé, examined the autocorrelation of Lyα clouds (along the line of sight) in detail utilizing a hydrodynamic simulation of Lyα clouds in a cold dark matter universe with a cosmological constant, comparing it to that of mass and galaxies. The correlation strength of Lyα clouds is somewhat weaker than that of the underlying matter, which in turn should be weaker than that of galaxies (biased galaxy formation). On the scales probed, $10-300$km/s, higher density, higher optical depth, higher column density Lyα clouds are more strongly clustered than lower density, lower optical depth, lower column density regions, with the difference being larger at small separations and smaller at large separations. Thus, a consistent picture seems to emerge: the correlation strength for a given set of objects is positively correlated with their characteristic global density and the differences among the correlations of galaxies, Lyα clouds and mass reflect the differences in density that each trace. Significant positive correlations with a strength of $0.1-1.0$ are found for Lyα clouds in the velocity range $50-300$km/s. This effect should be observable. The correlation function of Lyα clouds seems to be a monotonically decreasing function of separation, indicating that correlation strength should be less than 0.1 at $\Delta v > 300$km/s, where the simulation box was too small to give a reliable measure.

Among the correlational measures examined, an optical depth correlation function may serve as the best correlational measure. It reasonably faithfully represents the true correlation of the underlying matter, enabling a better indication of both matter correlation and the relationship between galaxies and Lyα clouds. Furthermore, it appears to be an alternative to the conventional line-line correlation function with the virtue that it does not require ambiguous post-observation fitting procedures such as those commonly employed in the conventional line-finding methods. Neither does it depend sensitively on the observational resolution (e.g., FWHM), insofar as the clouds are resolved (i.e., the FWHM is smaller than the line width). Conveniently, it can be easily measured with the current observational sensitivity without being contaminated significantly by the presence of noise, if one chooses an appropriate optical depth floor value τ_{min} (an adjustable parameter) say, ≤ 2.0.

Cen, in collaboration with F. Governato, B. Moore, J. Stadel, G. Lake and T. Quinn, studied the dynamics of the Local group. The dynamics of Local Group and its environment provide a unique challenge to cosmological models. The velocity field within 5h^{-1} Mpc of the Local Group (LG) is extremely ''cold.'' The deviation from a pure Hubble flow, characterized by the observed radial peculiar velocity dispersion, is measured to be 60 km/s. The local velocity field was compared with similarly defined regions extracted from N-body simulations of a universe dominated by cold dark matter. This test yields a strong discriminator between models that have different mean mass densities. Neither the $\Omega=1$ (SCDM) or $\Omega=0.3$ (OCDM) cold dark matter models can produce a single candidate Local Group that is embedded in a region with such small peculiar velocities. These models, produce velocity dispersion between 300–700 km/s and 150–300 km/s respectively, more than twice the observed value.

Although both CDM models fail to produce environments similar to those of our Local Group, they give rise to many binary systems that have similar orbital properties as the Milky Way-Andromeda system. The local bias of halos in the CDM ''Local Group'' environments is $\sim$ 1.5, independent of Ω.

Cen and Ostriker, in collaboration with M. Rauch, J. Miralda-Escudé, W.L.W. Sargent, T.A. Barlow, D.H. Weinberg, L. Hernquist, and N. Katz, measured the distribution function of the flux decrement $D=e^{-\tau}$ caused by Lyα forest absorption from intervening gas in the lines of sight to high redshift QSOs from a sample of seven high resolution QSO spectra obtained with the Keck telescope. The observed flux decrement distribution function (FDDF) is compared to the FDDF from two simulations of the Lyα forest: a ΛCDM model (with Ω =0.4, Λ=0.6) computed with the Eulerian code of Cen & Ostriker, and a standard CDM model (SCDM, with $\Omega = 1$) computed with the SPH code of Hernquist, Katz, & Weinberg. Good agreement is obtained between the shapes of the simulated and observed FDDFs for both simulations after fitting only one free parameter, which controls the mean flux decrement. The difference between the predicted FDDFs from the two simulations is small, and we show that it arises mostly from a different temperature in the low-density gas (caused by different assumptions that were made about the reionization history in the two simulations), rather than differences between the two cosmological models *per se*, or numerical effects in the two codes which use very different computational methods.

A measurement of the parameter $\mu \propto \Omega_b^2 h^3/\Gamma$ (where Γ is the HI ionization rate due to the ionizing background) is obtained by requiring the mean flux decrement in the simulations to agree with the observed one. Estimating the lower limit $\Gamma > 7\times10^{-13}$ s^{-1} from the abundance of known QSOs, they derive a lower limit on the baryonic matter density, $\Omega_b h^2 > 0.021(0.017)$ for the ΛCDM (SCDM) model. The difference between the lower limit inferred from the two models is again due to different temperatures in the low-density gas. Adopting a fixed Ω_b, the measurement of $\mu(z)$ allows a determination of the evolution of the ionizing radiation field with redshift. The models predict an intensity that is approximately constant with redshift, which is in agreement with the assumption that the ionizing background is produced by known quasars for $z<3$, but requires additional sources of ionizing photons at higher redshift given the observed rapid decline of the quasar abundance.

W.N. Colley, J. Richard Gott III and C. Park studied the topology of the fluctuations in the microwave background found in the COBE 4-year results. The topology is measured by the genus $g(\nu)$ which is defined as the number of hot spots minus the number of cold spots as a function of temperature threshold. Their results are in beautiful agreement with the theoretical curve expected for a Gaussian random-phase distribution: $g(\nu) \propto \nu \exp(-\nu^2/2)$ where ν (in terms of standard deviations) defines the area fraction f below the temperature threshold. These results are therefore consistent with the standard inflationary-big bang model in which the density fluctuations are due to random quantum fluctuations in the early universe.

Gott, Cen and Ostriker examined how the 3D topology of galaxy clustering is expected to vary by galaxy type. Spiral and SO galaxies should display a random phase sponge-like topology, but elliptical galaxies, which form earlier and have more time to fall into clusters, should, by virtue of these non-linear effects, show more of a ''meatball'' topology with a preference for finding isolated clusters shown by a small shift to the left of the 3D genus curve. This effect is demonstrated using the Ostriker and Cen hydrodynamical cosmological simulations, which incorporate not only gravity but also gas dynamics. This is a subtle but measurable effect, which shows up in the hydrodynamic simulations but not in ones where galaxies are picked by a simple biasing scheme that identifies peaks in the initial mass distribution. This effect could be measured in the Sloan Digital Sky Survey redshift sample where there will be a sufficient volume studied and it will be possible to type the galaxies automatically. Thus one can use the topology statistics to probe the details of the galaxy and large-scale structure formation process.

With N. Gnedin (MIT and UCB), Ostriker completed two papers (Ostriker & N. Gnedin, 1996; N. Gnedin & Ostriker, 1997), describing very high resolution simulations of the early formation of nonlinear structure in the Universe. In the first of these, they noted that current observational evidence strongly favors a conventional recombination of ionized matter subsequent to redshift z = 1200, followed by reionization prior to redshift z = 5 and computed how this would have occurred in a standard scenario for the growth of structure. They showed by direct, high-resolution numerical simulations (of a COBE normalized CDM + Λ model) that reheating will occur in the interval $20>z>7$, followed by reionization and accompanied by a significant increase in the Jeans mass. However, the evolution of the Jeans mass does not significantly affect star formation in dense, self-shielded clumps of gas, which are detached from the thermal evolution of the rest of the universe. On average, the growth of the Jeans mass tracks the growth of the nonlinear mass scale, a result they suspect is due to nonlinear feedback effects. Cooling by molecular hydrogen leads to a burst of star formation prior to reheating, which produces Population III stars with Ω^* reaching $10^{-5.5}$ and $\overline{Z}/Z_\odot$ reaching $10^{-3.7}$ by $z\sim14$. Star formation subsequently slows down as photodestruction and the rise of the temperature deplete molecular hydrogen. At later times, $z<10$, when the characteristic virial temperature of gas clumps reach 10^4 degrees, star formation increases again as hydrogen line cooling becomes efficient. Objects containing Population III stars accrete mass with time and, as soon as they reach 10^4 K virial temperature, engage in renewed star formation and turn into normal Population II objects having an old Population III, metal-poor component. In the second work (astro-ph/9612127), they simulated a plausible cosmological model in considerable physical and numerical detail through the successive phases of reheating (at $10<z<20$), formation of POP III stars at $z=15$, with subsequent reionization at $z=7$. They assumed an efficiency of high mass star formation appropriate to leave the universe, after it becomes transparent, with an ionizing background $J_{21}=0.4$ (at $z=4$), near the observed value. Since the same stars produce the ionizing radiation and the first generation of heavy elements, a mean metallicity of $\overline{Z}/Z_\odot=1/200$ is produced in this early phase, but there is a large variation about this mean, with the high density regions having $\overline{Z}/Z_\odot=1/30$ and low density regions having essentially no metals. Reionization, when it occurs, is very rapid, which will leave a signature which may be detectable by very large area meter-wavelength radio instruments. Also, the background UV radiation field will show a sharp drop from 1Ryd to 4Ryd due to absorption edges. The simulated volume is too small to form L^* galaxies, but the smaller objects which are found in the simulation obey the Faber-Jackson relation.

In order to explore theoretically this domain of ''the end of the dark ages'' quantitatively, numerical simulations must have a mass resolution of the order of $10^{4.5}M_\odot$ in baryons, high spatial resolution (1 kpc) to resolve strong clumping, and allow for detailed and accurate treatment of both the radiation field and atomic/molecular physics.

In more observationally oriented work (Colley, *et al.*, 1996) on the Hubble Deep Field, Ostriker, with W. Colley (graduate student) and J. Rhoads and D.N. Spergel, concluded that the small faint images are not separate galaxies but pieces of larger ones (most likely star forming regions). It had been suggested that faint source counts continue to rise to the completeness limit of the data, implying a very large number of galaxies. The two-point angular correlation function and number-magnitude relation of sources were used to assess the nature of the sources in the HDF. They found that the correlation peaks between 0.''25 and 0.''4 with amplitude of 2 or greater and is much higher for the smallest objects. This angular scale corresponds to physical scales of order 1 kpc for redshifts $z \gtrsim 1$. The correlation must therefore derive from objects with subgalactic separations. At faint magnitudes, the counts satisfy the relation number $\propto 1/\text{flux}$, which is expected for images that are subdivisions of larger ones.

Several explanations for these observed correlations are possible, but a conservative explanation can suffice to produce their results. Since high-redshift space ($z \gtrsim 0.5$) dominates the volume of the sample, observational redshift effects are important. Rest-frame ultraviolet radiation appears in the HDF's visible and near-UV bands, and surface brightness dimming enhances the relative brightness of unresolved objects versus resolved objects. Both work to increase the prominence of compact star-forming regions over diffuse stellar populations. Thus, a ''normal'' gas-rich galaxy at high redshift can appear clumpy and asymmetric in the visible bands. Form sufficiently faint and distant objects, the compact star-forming regions in such galaxies peak above undetectable diffuse stellar backgrounds. Their results do not exclude asymmetric formation or fragmentation scenarios.

In a subsequent paper, (Colley, *et al.*, 1997), Ostriker, with W. Colley, O.Y Gnedin (graduate students) and J.E. Rhoads, investigated the dynamics of the ''small galaxies'' in the Hubble Deep field, concluding that it was unlikely that we are witnessing accretion events, and more likely that we are simply seeing bright spots in irregular star forming systems. The previous work had found a significant angular correlation of faint, high color-redshift objects on scales below one arcsecond, or several kiloparsecs in metric size. A correlation at this scale is most likely due to physical associations. They examined the correlation and nearest neighbor statistics to conclude that 38% of these objects in the HDF have a companion within one arcsecond (or about 6 kpc), three times the number expected in a random distribution with the same number of objects; the total excess approaches 1.5 objects for separations of 10 arcseconds. They next examined three possible dynamical scenarios for these object multiplets: 1) the objects are star-forming regions within normal galaxies, whose disks have been relatively dimmed by K-correction and surface brightness dimming; 2) they are fragments merging into large galaxies; 3) they are satellites accreting onto parent normal L^* galaxies. They found that hypothesis 1 is most tenable. First, large galaxies in the process of a merger formation would have accumulated too much mass in their centers ($5\times10^{12}M_\odot$ inside 2 kpc) to correspond to any abundant category of present day objects. Second, accretion by dynamical friction occurs with a predictable slope in density vs. radius that is not seen among the faint HDF objects. Since the dynamical friction time is roughly 1 Gyr, a steady state should have been reached by redshift $z \lesssim 5$. In the context of these two dynamical scenarios, they consider the possible effects of a gradient in mass-to-light ratio caused by induced star formation during infall. They noted that star-forming regions within galaxies clearly present no dynamical problems, but also that large spirals would still appear as such in the HDF, which leads the collaborators to favor a scenario in which the faint compact sources in the HDF are giant star-forming regions within small normal galaxies, such as Magellanic irregulars. Last they noted that the ''excess'' number of correlated objects near a given faint source approaches 1.5, suggesting that the previous counts of objects have overestimated the number of galaxies by a factor of 2.5, while underestimating their individual luminosities by the same factor.

Ostriker completed a paper, (Ciotti & Ostriker, 1997) with Luca Ciotti (Bologna), arguing that quasars and cooling flows are different aspects of the same phenomenon. They presented a new class of solutions for the gas flows in elliptical galaxies containing massive central black holes (BH). Modified King model galaxies are assumed. Two source terms operate: mass loss from evolving stars, and a secularly declining heating by SNIa. All relevant atomic physical processes are modeled in detail. Like the previous models investigated by Ciotti, *et al.*, (1991), these new models first evolve through three consecutive evolutionary stages: wind, outflow, and inflow. At this point the presence of the BH alters dramatically the subsequent evolution, because the energy emitted by the BH can heat the surrounding gas to above virial temperatures, causing the formation of a hot expanding central bubble. Short and strong nuclear bursts of radiation are followed by longer periods during which the X-ray galaxy emission comes form the coronal gas (L_x). The range and approximate distribution spanned by L_x are found to be in accordance with observations of X-ray early type galaxies. Moreover, although high accretion rates occur during bursting phases when the central BH has a luminosity characteristic of QSOs, the total mass accreted is very small when compared to that predicted by stationary cooling-flow solutions and are in accord with putative BH nuclear masses. In the bursting phases L_x is low and the surface brightness profile is very low compared to pre-burstor to cooling flow models. They propose that these new models, while solving some long-standing problems of the cooling flow scenario, can provide a unified description of QSO-like objects and X-ray emitting elliptical galaxies, these being the same objects observed at two different evolutionary phases.

A major breakthrough in the observations of gamma-ray bursts was the detection of ''afterglows'' in X-ray, optical and radio domains, following rapid and accurate positions obtained with the BeppoSAX satellite. In order to explain the original energy source. Paczynski (1997) proposed a model of a ''hypernova,'' a massive star with the spin energy of its collapsed core rapidly transported to the envelope by a super-strong magnetic field. If this model is correct then gamma-ray bursts should appear in or near star forming regions at moderate redshifts.

Andrew Ulmer (graduate student), working under the supervision of B. Paczynski, developed a model of stellar tidal disruption by a close passage near a supermassive black hole, with the emphasis on the observable effects of such a phenomenon. Ulmer (1997) argued that the object is likely to appear as an optical-UV transient source in a galactic nucleus, and may be detectable in ongoing supernovae searches and also through ''fossil'' ionized nebulae near galactic nuclei.

P.S. Udomprasert (undergraduate) carried out senior thesis research with Knapp on optical and infrared measurements of interstellar dust masses in early-type galaxies, analyzing data for a sample of 64 nearby elliptical and S0 galaxies. The optical data are from an analysis of HST images of galaxy cores by van Dokkum and Franx (1995),, that found dust lanes in about half of the galaxies. Udomprasert and Knapp compared these results with dust masses derived from far- infrared flux measurements. They found that: SO galaxies contain 2 - 3 times as much dust on average as do elliptical galaxies; elliptical galaxies contain 10^{-2} to 10^{-3} of the amount of dust found in spiral galaxies of similar luminosity; the statistics of the detection rates suggest that most or all early-type galaxies contain interstellar dust; the dust in these systems is fairly similar in its properties to that in the Galaxy; the far-infrared observations detect much more dust (by about a factor of 100) than do the HST observations, showing that the dust is in structures extending well outside the galaxy cores; that the dust content is uncorrelated with either luminosity or internal structure; and that dusty elliptical galaxies are much more likely to contain non-thermal radio emitting cores than are galaxies with low dust content.

Michael Richmond continued to investigate the properties of supernovae, in concert with a group of colleagues at the University of California at Berkeley. Using a new robotic telescope, which started regular operations in November, 1996, they discovered the Type II Supernova 1997bs in April, 1997. The KAIT (Katzman Automatic Imaging Telescope) has been monitoring SN 1997bs and several other nearby supernovae regularly, in order to make precise measurements of supernova light curve shapes.

Richmond has been working for several years with a group of amateur astronomers who are building their own CCD cameras. The Amateur Sky Survey (TASS) plans to measure repeatedly the stars in a three-degree band around the celestial equator between sixth and thirteenth magnitude, in the *V* and *I* passbands. Several members of the group gave presentations at the summer 1997 AAS meeting in Winston-Salem, North Carolina. Richmond created and maintains the TASS home page on the World-Wide Web.

Maki Suginohara (visiting student), Tatsushi Suginohara and David Spergel explored the possibility of detecting the signature of gravitational lensing in the microwave background by cross-correlating cosmic microwave background radiation fluctuations with redshift surveys. Density inhomogeneities along the line-of-sight distort fluctuations in the cosmic microwave background. Usually, this effect is thought of as a small second-order effect that mildly alters the statistics of the microwave background fluctuations. They show that there is a first-order effect that is potentially observable if they combine microwave background maps with large redshift surveys. They introduce a new quantity that measures this lensing effect, $\langle T(\delta\theta\cdot\nabla T)\rangle$, where T is the microwave background temperature and $\delta\theta$ is the lensing due to matter in the region probed by the redshift survey. They show that the expected signal is first order in the gravitational lensing bending angle, $\langle(\delta\theta)^2\rangle^{1/2}$, and find that it should be easily detectable, (S/N) $\sim$ 15-35, if they combine the Microwave Anisotropy Probe satellite and Sloan Digital Sky Survey data. Measurements of this cross-correlation will directly probe the ''bias'' factor, the relationship between fluctuations in mass and fluctuations in galaxy counts.

Matias Zaldarriaga (MIT) and Spergel studied the autocorrelation function of CMB polarization anisotropies and their cross correlation with temperature fluctuations as probe of the causal structure of the universe. Because polarization is generated at the last scattering surface, models in which fluctuations are causally produced on sub-horizon scales cannot generate correlations on scales larger then $\sim 2^o$. Inflationary models, on the other hand, predict a peak in the correlation functions at these scales: its detection would be definitive evidence in favor of a period of inflation. This signal could be detected with the next generation of satellites.

Jeremy Kepner (graduate student), Arif Babul(NYU) and Spergel explored the effects of a background radiation field on the formation of dwarf galaxies. One of the largest uncertainties in understanding the effect of a background UV field on galaxy formation is the intensity and evolution of the radiation field with redshift. This work attempts to shed light on this issue by computing the quasi-hydrostatic equilibrium states of gas in spherically symmetric dark matter halos (roughly corresponding to dwarf galaxies) as a function of the amplitude of the background UV field. They integrate the full equations of radiative transfer, heating, cooling and non-equilibrium chemistry for nine species: H, H^+, H^-, H_2, H_2^+, He, He^+, He^{++}, and e^-. As the amplitude of the UV background is decreased the gas in the core of the dwarf goes through three stages characterized by the predominance of ionized (H^+), neutral (H) and molecular (H_2) hydrogen. Characterizing the gas state of a dwarf galaxy with the radiation field allows us to estimate its behavior for a variety of models of the background UV flux. The results indicate that a typical radiation field can easily delay the collapse of gas in halos corresponding to 1-σ CDM perturbations with circular velocities less than 30 km/s.

M. Zaldarriaga, D. Spergel and U. Seljak (CfA) explored how microwave background experiments could be used to constrain cosmology parameters. They used a high- accuracy computational code to investigate the precision with which cosmological parameters could be reconstructed by future cosmic microwave background (CMB) experiments, in particular the two satellite missions MAP and Planck Surveyor (COBRAS/SAMBA). They identify several parameter combinations that could be determined with a few percent accuracy with MAP and the Planck Surveyor, as well as some degeneracies among the parameters that cannot be accurately resolved with the temperature data alone. These degeneracies can be broken by other astronomical measurements. Polarization measurements can significantly enhance the science return of both missions by allowing accurate determination of cosmological parameters, by enabling the detection of gravity waves and by probing the ionization history of the universe. They also address the question of how Gaussian the likelihood function is around the maximum and whether gravitational lensing changes the constraints.

Ue-li Pen (CfA) and David Spergel explored the physics of a String-Dominated Universe. The string-dominated universe locally resembles an open universe, and fits dynamical measures of power spectra, cluster abundances, redshift distortions, lensing constraints, luminosity and angular diameter distance relations and microwave background observations. They show examples of networks, which might give, rise to recent string-domination without requiring any fine-tuned parameters. They discuss how future observations can distinguish this model from other cosmologies.

J. Dalcanton, D.N. Spergel and F. Summers (postdoc, Princeton) developed a theory for the formation of disk galaxies. They present a scenario for the formation of disks which explains not only the properties of normal galaxies, but the properties of the population of low surface brightness galaxies (LSBs) as well. They use a gravitationally self-consistent model for disk collapse to calculate the observable properties of disk galaxies as a function of mass and angular momentum of the initial protogalaxy. The model naturally produces smooth, asymptotically flat rotation curves and exponential surface brightness profiles over many disk scale lengths. In this scenario, low mass and/or high angular momentum halos naturally form low baryonic surface density disks, which will tend to be low surface brightness. Theoretical and numerical calculations suggest galaxy halos should form with a wide range of mass and angular momenta, and thus, the disks, which form within these halos, should have a wide range of surface brightness' and scale lengths. They use theoretical predictions for the distribution of halo masses and angular momenta to explicitly calculate the expected number density of disk galaxies as a function of central surface brightness and disk scale length. The resulting distribution is compared to the observed properties of galactic disks, and is shown to explain the range of observed disk properties, including the cutoff in the maximum disk scale length as a function of surface brightness. They also show that disk instabilities explain the observed lack of high surface density disks. The calculated distribution of disk properties also suggests that there are large numbers of galaxies, which remain undetected due to biases against galaxies with either low surface brightness or small-scale length. They quantify this by calculating the difference between the intrinsic luminosity function and the luminosity function, which would be measured in a galaxy survey with a given limiting surface brightness. They show that current measurements of the galaxy luminosity function may be missing more than half of all L_* galaxies, and an even larger fraction of faint galaxies, given the correlation between mass and surface brightness. The likely underestimate of the luminosity density is also expected to be large. They discuss how this affects observations of the ''faint blue galaxy'' population.

Dalcanton, Spergel and Summers also investigated the dynamics of galaxies as a function of surface brightness. They showed that, in the absence of any systematic change in the ratio of disk mass to disk luminosity, galaxies of all surface brightness' should lie on the same Tully-Fisher relation. The models also show systematic changes in the shape of the rotation curve as a function of angular momentum, which leads to low surface brightness galaxies having slowly rising rotation curves. Furthermore, because high angular momentum LSB disks have their baryonic mass spread over a larger area than normal galaxies of comparable mass, LSB disks contribute very little to the observed dynamics of the galaxy. Thus, LSBs provide a very effective tracer of the shape and mass profile of the dark matter halo, out to proportionally larger radii than is possible to observe with normal galaxy rotation curves.

J. Dalcanton (OCIW), D.N. Spergel, J.E. Gunn, M. Schmidt (Caltech) and D.P. Schneider (Penn State) presented results of a large area CCD survey for low surface brightness galaxies (LSBs) that reaches central surface brightness' of 25mag/arcsec^2 in V. They have analyzed 17.5 $(deg)^2$ of transit scan data, and identified a statistical subset of 7 pure disk LSB's with central surface brightness' fainter than $\mu_0 = 23$ Vmag/arcsec^2 and with angular exponential scale lengths larger than $\alpha = 2.5''$. The LSB detection is entirely automated, and the selection efficiency of the survey is well quantified. After correcting for the selection efficiency, they find a surface density of $4.1^{+2.6}_{-2.1}$galaxies / degree^2 for LSBs in the considered range of μ_0 and α (90% confidence levels), with the largest correction being due to the area lost behind bright stars, and the difficulty in detecting LSBs with small angular sizes. They have measured redshifts to the final sample of LSBs, and find them to be at distances comparable to those probed by large galaxy catalogs, and to have intrinsic scale lengths of $1.7 - 3.6_{50}^{-1}$kpc, also comparable to normal galaxies. They use the redshifts and the selection efficiency to calculate the number density in LSBs with $23 < \mu_0 < 25$ Vmag/arcsec^2 and find $\mathcal{N} = 0.01^{+0.006}_{-0.005}$ galaxies h_{50}^3 Mpc^{-3}, with 90% confidence. The measurement of the absolute number density of LSBs probably represents a lower limit, due to very strong biases against LSBs with bulges or edge-on LSBs in the sample. Comparing the LSB number density to the number density of normal galaxies with either similar scale lengths or similar luminosities, they find that the number density of LSBs with $23 < \mu_0 < 25$ Vmag/arcsec^2 is comparable to or greater than the number density of normal galaxies. The luminosity density in LSBs is comparable to the luminosity density of normal galaxies with similar luminosities, but is a factor of 3-10 smaller than the luminosity density of normal galaxies with similar scale lengths. The relative LSB number density and luminosity density agrees well with the theoretical predictions of Dalcanton, Spergel and Summers. The redshift-space distribution of the LSBs suggests that the trend for low surface brightness galaxies to have weak small scale correlations may continue to the fainter surface brightness' covered in this survey.

Michael Strauss continued his work on studies of the large-scale distributions and motions of galaxies. In collaboration with Jeff Willick (Stanford), Avishai Dekel (Hebrew University), and Tsafrir Kolatt (UC Santa Cruz), he carried out a detailed likelihood analysis comparing existing Tully-Fisher data with the IRAS redshift survey. Unlike previous comparisons of peculiar velocity and redshift data, this worked directly with the raw Tully-Fisher data themselves, and thus involved a minimal amount of massaging of the data. Thus the calibration of the Tully-Fisher data themselves was included as part of the analysis, and correction for Malmquist bias is part and parcel of the technique itself. It was found that the Tully-Fisher and IRAS data are consistent with one another as expected from linear gravitational instability theory and linear biasing. The small-scale velocity dispersion of galaxies was found to be $125\pm 20\mathrm{kms}^{-1}$, and $\beta\equiv\Omega^{0.6}/b=0.49\pm 0.07$.

In collaboration with Willick, Dekel, Stephane Courteau (DAO), David Burstein (Arizona State University) and Sandra Faber (UC Santa Cruz), Strauss published the Tully-Fisher data upon which the above analysis was based, with the most reliable and uniform calibration available.

In collaboration with Daniel Koranyi (CfA), Strauss published a critique of the results of I. Segal, *et al.*, who used the IRAS redshift survey to argue that the observed correlation of fluxes and redshifts in the sample ruled out the Hubble law, and favored a universe in which the redshifts of galaxies are proportional to the square of their distances. They repeated Segal's analysis, and were able to show that this conclusion followed from a systematic error in the way Segal, *et al.*, calculated the luminosity function of galaxies. Correcting for this error, they found that the techniques of Segal, *et al.*, did in fact not distinguish very strongly at all between the two cosmologies. However, adding the additional assumption that the galaxy distribution is homogeneous on large scales allowed them to rule out the quadratic redshift-distance law unambiguously.

In collaboration with Rita Kim (Princeton), Strauss developed a parameterized form for the observed distribution function of counts in cells of galaxies. Fitting this form to observed data allowed them to constrain the skewness and kurtosis of the galaxy distribution. They were able to show with the aid of N-body simulations that this method gives unbiased results, which are more robust in several ways from those determined by the traditional moments method.

In collaboration with Luigi Guzzo (Milano), Karl Fisher (U. Texas), and Riccardo Giovanelli and Martha Haynes (Cornell), Strauss calculated the small-scale velocity dispersion of galaxies of different morphological types in the Pisces-Perseus redshift survey. They found that the velocity dispersion of spiral galaxies was considerably smaller than that of ellipticals, and that the spiral velocity dispersion was much more robust to the presence or absence of rich clusters in the sample, suggesting that they measure the velocity dispersion in the field.

Strauss wrote a review of large-scale bulk flows, that will appear in the proceedings of a conference, ''Critical Dialogues in Cosmology,'' which took place in Princeton in summer 1996.

Turner, in collaboration with T. Kundić (Caltech), W. Colley, J. R. Gott, Y. Wang, J. Rhoads (KPNO), S. Malhotra (IPAC), J. Wambsganss (AIP), L. Bergeron, K. Gloria and D. Long (all of APO), made a robust determination of the time delay in 0957+561A,B and thus measured the global value of Hubble's constant using Refsdal's method. Continued photometric monitoring of the gravitational lens system 0957+561A,B in the g and r bands with the Apache Point Observatory (APO) 3.5 m telescope during 1996 showed a sharp g band event in the trailing (B) image light curve at the precise time predicted in an earlier paper. The prediction was based on the observation of the event during 1995 in the leading (A) image and on a differential time delay of 415 days. This success confirmed the so called ''short delay,'' and the absence of any such feature at a delay near 540 days rejected the ''long delay'' for this system, thus resolving a long standing controversy. A series of statistical analyses of the APO light curve data yielded a best fit delay of 417 ± 3 days (95% confidence interval) and demonstrated that this result is quite robust against variations in the analysis technique, data subsamples and assumed parametric relationship of the two light curves. Recent improvements in the modeling of the lens system (consisting of a galaxy plus a galaxy cluster) allow derivation of the global (at $z=0.36$) value of Hubble's constant H_0 using Refsdal's method, a simple and direct (single step) distance determination based on experimentally verified and securely understood physics and geometry. The result is $H_0=64\pm 13$ km/s/Mpc (for $\Omega=1$) where this 95% confidence interval is dominantly due to remaining lens model uncertainties. However, it is reassuring that available observations of the lensing mass distribution over constrain the model and thus provide an internal consistency check on its validity. *This determination of the extragalactic distance scale (10% accurate at 1σ) is now of comparable quality, in terms of both statistical and systematic uncertainties, to those based on more conventional techniques.*

Turner, S. Malhotra (IPAC) and J. Rhoads (KPNO) obtained evidence for dusty gravitational lenses. Foreground galaxies that amplify the light from background quasars may also dim that light if the galaxies contain enough dust. Extinction by dust in lenses could hide the large number of lensed systems predicted for a flat universe with a large value of the cosmological constant Λ. They looked for one signature of dust, namely reddening, by examining optical-infrared colors of gravitationally lensed images of quasars. They found that the lensed systems identified in radio and infrared searches have redder optical-IR colors than optically selected ones. This could be due to a bias against selecting reddened (hence extinct) quasars in the optical surveys, or due to the differences in the intrinsic colors of optical and radio quasars. Comparison of the radio-selected lensed and unlensed quasars shows that the lensed ones have redder colors. They therefore concluded that at least part of the color difference between the two lens samples is due to dust. From the color difference between lensed and unlensed radio quasars (and assuming Galactic extinction law) they could reconcile a large cosmological constant ($\Lambda=0.9$) with the number of lensed systems observed in flux limited optical surveys. These results substantially weaken the strongest constraint on cosmological scenarios that invoke a non-zero cosmological constant to explain age discrepancy problems, satisfy predictions of inflationary models of the early universe and play a role in large-scale structure formation models. They also raise the prospect of using gravitational lenses to study the interstellar medium in high redshift galaxies.

Turner and M. Umemura (Tsukuba University) examined the possibility that a population of relic massive black holes, perhaps constituting an important component of the dark matter, might be indirectly detected via their occasional very strong gravitational lensing of individual luminous stars in distant external galaxies. For plausible, and in some respects conservative, values of the relevant physical parameters, they showed that such events might be detected either in wide area surveys reaching routine CCD magnitude limits (such as the Sloan Digital Sky Survey) or in small field, very deep images (such as the HDF). Thus, it would be a challenging but not impossible task to detect or place limits on a cosmic population of relic massive black holes.

Yun Wang (while in Fermilab) collaborated with Ed Turner (Princeton) on part II of their work on statistics of extreme gravitational lensing events, the finite shear case. They considered an astrophysical system with a population of sources and a population of lenses. For each pair of source and lens, 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 studied the physics and statistics of EGLE for the case in which the shear is larger or comparable to the finite source size. They found that the presence of shear has only a small effect on the EGLE statistics.

Yun Wang collaborated with Pierre Sikivie (University of Florida) and Igor Tkachev (Ohio State) on a secondary infall model of galactic halo formation and the spectrum of cold dark matter particles on Earth. The spectrum of cold dark matter particles on Earth is expected to have peaks in velocity space associated with particles which are falling onto the Galaxy for the first time and with particles which have fallen in and out of the Galaxy only a small number of times in the past. They obtained estimates for the velocity magnitudes and the local densities of the particles in these peaks. To this end they used the secondary infall model of galactic halo formation which they had generalized to take account of the angular momentum of the dark matter particles. The new model is still spherically symmetric and it admits self similar solutions. In the absence of angular momentum, the model produces flat rotation curves for a large range of values of a parameter ϵ which is related to the spectrum of primordial density perturbations. They found that the presence of angular momentum produces an effective core radius, i.e., it makes the contribution of the halo to the rotation curve go to zero or zero radius. The model provides a detailed description of the large-scale properties of galactic halos including density profiles, extent and total mass. They obtained predictions for the kinetic energies of the particles in the velocity peaks and estimates for their local densities as functions of the model parameters which are the amount of angular momentum, the age of the universe and ϵ.

Yun Wang collaborated with Turner (Princeton) on the caustics, critical curves and cross sections for gravitational lensing by disk galaxies. They studied strong gravitational lensing by spiral galaxies, modeling them as infinitely thin uniform disks embedded in singular isothermal spheres. They derived general properties of the critical curves and caustics analytically. The multiple-image cross section is a sensitive function of the inclination angle of the disk relative to the observer. They computed the inclination-averaged cross section for several sets of lensing parameters. For realistic disk mass and size parameters, they found that the cross section for multiple imaging is increased by only a modest factor and *no* dramatic increase in the optical depth for strong lensing of QSOs would be expected. However, the cross section for high magnifications is significantly increased due to the inclusion of a disk, especially for nearly edge-on configurations; due to the strong observational selection effects favoring high magnifications, there might be significant consequences for lensing statistics.

2.2 Stellar and Galactic Dynamics

With Pawan Kumar (MIT, IAS), Goodman studied the importance of three-mode couplings for tidal capture of stars in globular clusters. Tidal capture is the formation of a binary from two stars initially on a hyperbolic (unbound) relative orbit, as a result of excitation of large-amplitude oscillations in the stellar envelopes during pericentral passage. Other workers have shown that tidal capture can sometimes be only temporary, because the transfer of energy from the orbit to the oscillations is in principle reversible; the linear damping times of the large-scale oscillations are of order ten thousand years. Goodman and Kumar have shown, however, that oscillations large in amplitude and scale readily destabilize numerous short-wavelength g-modes through three-mode couplings. The g-modes are quickly damped by radiative diffusion. As a result of this nonlinear process, the effective damping time of the large-scale modes is reduced to less than a year, and tidal capture is effectively irreversible.

Siang Peng Oh (graduate student) and Goodman have reinvestigated the efficiency of turbulent convection for circularizing the orbits of close binary stars. Older binaries are circular at longer orbital periods, which suggests that circularization proceeds during the main sequence phase. Since the periods of interest are shorter than the turnover time of the largest convective eddies, it is believed that turbulent dissipation of the stellar tides (and hence of the binary's eccentricity) is partially suppressed. The degree of suppression, however, is disputed. Via new analytic and numerical calculations, Oh and Goodman find that the suppression is severe. Furthermore, they find that even without suppression, turbulent convection viscosity is unable to explain circularization of the longer period orbits during the main-sequence lifetimes of binaries containing solar-type stars.

Ostriker and O.Y. Gnedin completed three papers related to the dynamics of globular clusters. In the first of these (O. Gnedin & Ostriker, 1997a), they investigated the dynamical evolution of the Galactic globular cluster system in considerably greater detail than has been done hitherto, finding that destruction rates are significantly larger than given by previous estimates. For the evolution of individual clusters, they used a Fokker-Planck code including the most important physical processes governing the evolution: two-body relaxation, tidal truncation of clusters, compressive gravitational shocks while clusters pass through the Galactic disk, and tidal shocks due to passage close to the bulge. Gravitational shocks are treated comprehensively, using a recent result by Kundić & Ostriker that the $\langle \Delta E^2 \rangle$ shock-induced relaxation term, driving an additional dispersion of energies, is generally more important than the usual energy shift term $\langle \Delta E \rangle$. Various functional forms of the correction factor are adopted to allow for the adiabatic conservation of stellar actions in the presence of transient gravitational perturbation.

They used a recent compilation of the globular cluster positional and structural parameters, and a collection of radial velocity measurements. Two transverse to the line-of-sight velocity components were assigned randomly according to the two kinematic models for the cluster system (following the method of Aguilar, Hut, & Ostriker): one with an isotropic peculiar velocity distribution, corresponding to the present-day cluster population, and the other with the radially preferred peculiar velocities, similar to those of the stellar halo. They used the Ostriker & Caldwell and the Bahcall, Schmidt, & Soneira models for our Galaxy.

For each cluster in their sample, they calculated its orbits over a Hubble time, starting from the *present* observed positions and assumed velocities. Medians of the resulting set of peri- and apogalactic distances and velocities are used then as input for the Fokker-Planck code. Evolution of the cluster is followed up to its total dissolution due to a coherent action of all of the destruction mechanisms. The rate of destruction is then obtained as a median over the entire cluster sample.

They found that the total destruction rate is much larger than that given by Aguilar, Hut, & Ostriker with more than half of the present clusters (52% - 58% for the Ostriker & Caldwell model, and 75% - 86% for the Bahcall, Schmidt, & Soneira model) destroyed in the next Hubble time. Alternatively put, the typical time to destruction is comparable to the typical age, a result that would follow from (but is not required by) an initially power law distribution of destruction times. They discussed some implications for a past history of the globular cluster system and the initial distribution of the destruction times, raising the possibility that the current population is but a very small fraction of the initial population with the remnants of the destroyed clusters constituting presently a large fraction of the spheroid (bulge + halo) stellar population.

In the second paper, Ostriker and O. Gnedin (O. Gnedin & Ostriker, 1997b), utilized the dynamical theory developed in the first paper to describe how the observed luminosity function of globular clusters in external galaxies can function as a new and reasonably accurate distance indicator. Assuming the same initial luminosity function as in the Milky Way, they constructed an intrinsic distribution of globular clusters resulting from an isolated, passive evolution over the Hubble time of the true initial distribution. The galactic environment changes this distribution primarily through tidal shocks and dynamical friction. Their model explains, on a quantitative basis, the observed differences between the inner and outer populations of globular clusters in the Galaxy, M31, and M87. They can further calculate the amount of apparent brightening of the peak of the luminosity function due to destruction of low-mass clusters. Comparing the corrected peak with the center of the intrinsic distribution, they obtain distance moduli to the galaxies. Using this method they find $dm_{M31}=24.03\pm0.23$ and $dm_{M87}=30.81\pm0.17$, as compared to the current best estimates using other methods ($dm_{M31}=24.30\pm0.20$, $dm_{M87}=31.0\pm0.1$). This new method, coupled with *Hubble Space Telescope* observations, promises to provide an independent way of estimating distances to galaxies with recessional velocities $\lesssim$10,000 km s^{-1}, or $d\lesssim100h^{-1}$ Mpc. The surprising consistency of the predicted and observed distances supports the initial *Ansatz* that the mass functions of globular clusters in the three galaxies, spanning a wide range of masses, were universal at the birth of these systems.

Finally, in a more theoretically oriented paper, O. Gnedin and Ostriker examined the self-consistent response of stellar systems to gravitational shocks (including the effects of potential fluctuations driven by internal oscillations). Specifically, they studied the reaction of a globular star cluster to a time-varying tidal perturbation (gravitational shock), using self- consistent N-body simulations, and address two questions. First, to what extent is the cluster interior protected by adiabatic invariants. Second, how much further energy change do the postshock cluster oscillations produce and how much do they affect the dispersion of stellar energies. They found that when the cluster potential is fixed, the adiabatic corrections for the energy change follow a power-law in the adiabatic parameter $x\equiv\omega\tau, A(x)=(1+x^2)^{-5/2}$ for the shock durations of the order of the half-mass dynamical time for the cluster, $\tau\lesssim t_{\mathrm{dyn,h}}$. For more prolonged shocks, the adiabatic corrections become shallower, $A(x)=(1+x^2)^{-3/2}$ for $\tau=4t_{\mathrm{dyn,h}}$, approaching the prediction of the linear theory by Weinberg. When they allow for self-gravity and the oscillations, which follow the shock, the evolution of the potential causes significant changes in the energy of stars in the core, while the total energy of the system is conserved. Paradoxically, the post-shock potential fluctuations *reduce* the total amount of energy dispersion, $\langle \Delta E^2 \rangle$. The effect is small but real, and is due to the post-shock energy change being statistically anti-correlated with the shock induced energy change. These results are to be applied to Fokker-Planck calculations of evolution of globular clusters.

2.3 Stellar Astronomy and the Solar System

Jorissen and Knapp completed an analysis of the circumstellar properties of S stars in order to put these properties in perspective with current understanding of the evolutionary status of S stars, in particular the intrinsic/extrinsic dichotomy. This dichotomy states that only Tc-rich ('intrinsic') S stars are genuine thermally-pulsing asymptotic giant branch stars, possibly involved in the M–S-C evolutionary sequence. Tc-poor S stars are referred to as 'extrinsic' S stars, because they are the cooler analogs of barium stars, and like them, owe their chemical peculiarities to mass transfer across their binary system.

An extensive data set probing the circumstellar environment of S stars (IRAS flux densities, maser emission, CO rotational lines) was collected and critically evaluated. This data set combines new observations (13 stars were observed in the CO $J=2-1$ line and 3 in the CO $J=3-2$ line, with four new detections) with existing material (all CO and maser observations of S stars published in the literature). The IRAS flux densities of the S stars were re-evaluated by co-adding the individual scans, in order to better handle the intrinsic variability of these stars in the IRAS bands and possible contamination by Galactic cirrus.

In IR color-color diagrams, S stars were found to segregate into five distinct regions according to their Tc content and the ZrO/TiO, C/O and IR spectral indices. A simple radiative-transfer code was used to infer the chemical nature (carbonaceous or silicate) of the dust grains from the observed IR colors of the circumstellar shell. Comparison with the ($K-[12]$,$[25]-[60]$) color-color diagram showed that both carbon-rich and oxygen-rich dust shells are probably observed around S stars. The IR colors of S stars populating the region of the color-color diagram with small $K-[12]$ excess and moderate $[25]-[60]$ excess are best reproduced by carbon-rich dust. This result is consistent with the featureless appearance of their IRAS low resolution spectra (LRS classes S or F), as predicted for graphite or amorphous-carbon grains, with the absence of the silicate IR feature at 9.7 μm, and the absence of SiO, OH or H_2O maser emission.

Several S stars have large 60 μm excesses that are best explained by detached dust shells. For many of these stars, the 60 μm emission is resolved by the IRAS beam. The prototypical SC star FU Mon is among these. Since SC stars are believed to be in a very short-lived evolutionary phase where C/O = 1 within 1%, FU Mon may be a good candidate for the ‘interrupted mass-loss’ scenario advocated by Willems & de Jong (1988). The CO line profile of FU Mon is also peculiar in being quite narrow ($V_e=2.8kms^{-1}$), suggesting that mass loss has just resumed in this star.

Mass loss rates or upper limits have been derived for all S stars observed in the CO rotational lines, and range range from $<2\times10^8 M_\odot yr^{-1}$ for extrinsic S stars to $1\times10^{-5} M_\odot yr^{-1}$ (the Mira S star W Aql). These mass-loss rates correlate well with the $K-[12]$ color index, which probes the dust loss rate, provided that $95M>10^{-8}M_\odot sunyr^{-1}$. Small mass-loss rates are found for extrinsic S stars, consistent with their not being so evolved (RGB or E-AGB) as the Tc-rich S stars. This result does not support the claim often made in relation with symbiotic stars that binarity strongly enhances the mass-loss rate.

Ž. Ivezić, in collaboration with M. Elitzur (U. Kentucky) has continued to work on the scaling properties of radiative transfer through dust. They find that the spectral shape of the radiation processed by dust is independent of overall luminosity and geometrical size scale, when the inner boundary is controlled by dust sublimation. These scaling properties result in tight correlations among various observables, and enable systematic studies of large infrared databases. Together with A. Miroshnichenko (Pulkovo Observatory), they perform such studies for various classes of medium- and high mass young stellar objects (e.g., Herbig Ae/Be stars, B[e] stars). They find that the models of spherical dusty envelopes with roughly 1/r density distribution can explain IR emission from the majority of such sources, in contrast with the low-mass T Tau stars which require disk like geometry.

Ivezić and D. Christodoulou (Louisiana St. University) have searched IRAS database for young stars in HI high-velocity clouds (HVCs). Their results point to a low but significant star-formation rate in intermediate and high Galactic latitude HVCs. Such rate is sufficient to account for the existence of young blue stars born in the Galactic halo, and the nonprimordial metallicities inferred for some HVCs.

Ivezić, in collaboration with M. Groenewegen (MIP, Garching), A. Men’shchikov (PAS, Warsaw), and R. Szczerba (PAS, Toruń), has defined a set of benchmark problems for dust radiative transfer, and presented solutions obtained by three codes which implement different numerical schemes. These results are used for the verification of several new dust radiative transfer codes.

2.4 Galactic Astronomy and Interstellar Matter

B.T. Draine continued to work on theoretical astrophysics of the interstellar medium, with particular attention to photodissociation fronts and to interstellar dust.

The theory of stationary photodissociation fronts has been investigated by Draine & Bertoldi (1996). It is shown that overlap of the ultraviolet absorption lines of H_2 (neglected in much previous work) can often be important. New approximations are developed for the treatment of self-shielding when line overlap becomes important, and photodissociation front models including these effects are computed. The models are 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.

ISO observations of the S140 reflection nebula/photodissociation region have been analyzed and modelled using the theoretical models developed by Draine and Bertoldi. The ISO satellite has, for the first time, made possible observations of H_2 emission from rotationally excited levels of the ground vibrational state, in addition to emission from vibrationally-excited levels of H_2, and various atomic and ionic fine-structure lines. The observed intensities (Timmerman, *et al.*, 1996) show that a layer of the molecular gas in the S140 PDR is characterized by a surprisingly high kinetic temperature, in excess of 500K. Such high temperatures are theoretically surprising; the only previous evidence for such high temperatures was the analysis by Draine & Bertoldi (1996) of NGC 2023.

Radiation pressure has long been recognized to play an important role in grain dynamics because of the force exerted on grains by an anisotropic radiation field, but the torques exerted on dust grains by anisotropic radiation can also be dynamically important.

Draine and Joseph Weingartner (graduate student) studied the radiative torques exerted on irregular dust grains when they are illuminated by interstellar starlight. The theory underlying calculation of these torques is developed, and the torques are calculated for examples of irregular grains using a modified version of the DDSCAT code for calculating scattering and absorption by targets using the discrete dipole approximation. Radiative torques exerted on grains by the interstellar radiation field may result in spinup of the grains to superthermal rotation rates (Draine & Weingartner 1996). 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, both for producing superthermal rotation and for aligning dust grains with the local magnetic field. The effects of torques from moderately anisotropic starlight have been studied (Draine & Weingartner 1997). It is found that starlight torques appear to play a major role in the process of grain alignment. In many cases, it is found that radiative torques can bring about grain alignment much more rapidly than the paramagnetic dissipation process which is usually invoked.

A. Lazarian has continued developing the theory of grain alignment. One challenging problem was to describe quantitatively the alignment of the grain's principal axis of largest moment of inertia with the grain's angular momentum. Lazarian earlier established the fact that thermal fluctuations within the grain material make this alignment incomplete, but only a qualitative description was obtained at that time. Working with W. Roberge (Rensselaer), A. Lazarian obtained a detailed description of this process, thus opening an avenue of applications of this new effect in grain alignment theory.

The process of grain alignment, whether by radiative torques or the ''classical'' Davis-Greenstein mechanism of paramagnetic dissipation, characteristically involves ''crossover'' events, where the grain's angular velocity component along the grain's principal axis of largest moment of inertia changes sign. These crossover events are critical to the process of grain alignment, because the grain is easily disoriented during the period when its angular momentum is small. Lazarian and Draine (1997) have shown that previous analyses of the crossover process overlooked the subtle but very important effects of thermal fluctuations within the grain. When these fluctuations are taken into account, it is found that the larger grains — the ones, which are observed to be highly aligned in the interstellar medium — are much less susceptible to disorientation during crossover than had previously been believed. It seems paradoxical that thermal fluctuations can result in improved grain alignment; this happens because the thermal fluctuations cause the grain's spin axis to deviate from the direction of the angular momentum, which prevents the ''systematic'' torques from spinning the grain down to very small angular momenta during the ''crossover''-process. As a result, it is found that even without radiative torques acting, classical paramagnetic dissipation appears capable of achieving the observed degree of grain alignment, for plausible assumptions regarding grain properties.

Lazarian obtained new results relevant to the Gold mechanism for alignment of non-spherical grains, providing an analytical description of the alignment process in the presence of incomplete internal relaxation. He obtained good agreement between his results and available numerical data. Addressing the problem of Davis-Greenstein alignment of non-spherical grains, Lazarian obtained analytical expressions for their measure of alignment in the presence of incomplete internal alignment.

Lazarian, in collaboration with Roberge, studied paramagnetic alignment of grains subjected to cosmic rays. This study disproved a fallacy that cosmic rays provide an essential means for grain alignment.

Lazarian, in collaboration with M. Efroimsky (Harvard) and J. Ozik (Tufts), calculated measures of mechanical alignment for suprathermally rotating prolate grains. These results provide a quantitative foundation for the ''cross-section'' alignment mechanism introduced earlier by A. Lazarian.

Lazarian, in collaboration with A. Goodman and P. Myers (CfA), calculated alignment measures provided by various alignment mechanisms in dark clouds. These results explained earlier observations by A. Goodman.

Lazarian, in collaboration with D. Pogosyan (CITA), showed that Gaussian fluctuations can produce distinct filamentary patterns within galactic HI. These results can explain ubiquitous filaments that are observed within HI data cubes.

E.L. Fitzpatrick continued to work on studies of interstellar absorption lines. Fitzpatrick (1996) analyzed the pattern of interstellar gas-phase abundances of the elements Si, S, Mn, Cr, Fe, and Zn 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.

Fitzpatrick and Spitzer (1997) continued their multi-year study of the physical properties of individual interstellar clouds with a detailed examination of the line of sight towards the star HD 215733 in the Galactic halo. 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 a exceedingly complex line of sight, with more than 20 individual absorption components identified in the low- ionization species. 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. A paper describing these results were published in the *Astrophysical Journal*.

Fitzpatrick (1997) derived an empirical estimate of the oscillator strengths of the far-UV Mg II $\lambda\lambda$1239,1240 lines. The strong near-UV Mg II $\lambda\lambda$2796,2803 lines are generally highly saturated along most interstellar sightlines outside the local ISM and usually yield extremely uncertain estimates of Mg^+ column densities in interstellar gas. Since Mg^+ is the dominant form of Mg in the neutral ISM and since Mg is expected to be a significant constituent of interstellar dust grains, the far-UV lines are critical for assessing the role of this important element in the ISM. This study consisted of complete component analyses of the absorption along the lines of sight toward HD 93521 in the Galactic halo and ξ Per and ζ Oph in the Galactic disk, including all four UV Mg^+ lines and numerous other transitions. The three analyses yield consistent determinations of the $\lambda\lambda$1239,1240 f-values, with weighted means of $6.4\pm0.4\times10^{-4}$ and $3.2\pm0.2\times10^{-4}$, respectively. These results are a factor of $\sim$2.4 larger than a commonly used theoretical estimate, and a factor of $\sim$2 smaller than a recently suggested empirical revision. The effects of this result on gas- and dust-phase abundance measurements of Mg are discussed.

Jenkins and A. Peimbert (graduate student) analyzed Lyman and Werner band absorption features of interstellar molecular hydrogen in the UV spectrum of ζ Ori A. This spectrum was recorded over the wavelength interval $950-1150$Å at high resolution by the Interstellar Medium Absorption Profile Spectrograph (IMAPS) during the first flight of ORFEUS-SPAS, an instrument and spacecraft configuration launched into orbit and retrieved by the Space Shuttle (STS-51) in late 1993. H_2 toward ζ Ori A appears in three principal velocity components. One of these components shows velocity displacements and broadening for absorptions out of successively higher rotational levels. This behavior is unlike what is usually seen for H_2, where the profile shapes are virtually identical in shape, as one would expect for optical pumping in a thin medium. Using evidence from atomic lines at large and moderate negative velocities, Jenkins and Peimbert (1997) concluded that the strange behavior of the H_2 lines is probably caused by molecule formation behind a shock front. They proposed that this process is occurring in a collapsing column of warm, partly ionized gas that is recombining and cooling behind a bow shock created by the collision of a stellar wind with a foreground interstellar cloud.

For the analysis of interstellar or intergalactic absorption features that are somewhat resolved by a spectrograph, Jenkins has devised a method of correcting the apparent optical depths (as a function of velocity) to compensate for errors caused by very narrow, saturated structures inside the main profiles. The correction scheme can be applied only when two or more lines from the same absorber are observed, and it makes use of disparities in the scaling of the apparent optical depths with transition probabilities. The analysis method operates on the same principle as the interpretation of a curve-of-growth for the total equivalent widths of lines. In an article that discusses how the method works, Jenkins (1996) presents some very simple approximations to the exact formulae that can be applied in practice.

B. Paczynski and his associates worked on a major observing program aimed at detecting gravitational microlensing in our Galaxy (the Optical Gravitational Lensing Experiment — OGLE), and on projects that arose serendipitously from the OGLE. The most important new development is the full-scale operation of the new OGLE-2 telescope at the Las Campanas Observatory. This R/C 1.3-meter telescope has a permanently mounted 2k x 2k back-illuminated CCD camera. It is dedicated to massive photometric searches for variable objects: gravitational microlensing events and all other types of variable stars. Dr. A. Udalski of the Warsaw University Observatory and his associates developed all hardware and software. The instrument makes up to 50 million photometric measurements every clear night, and the data is processed on site within 24 hours. While the data has been flowing smoothly since January 1997, it will take till the end of 1997 before the first significant scientific results will be available.

B. Paczynski and his associates studied various effects, which affect quantitative analysis of microlensing data: the blending of images in crowded fields, the relation between the observed time scale and the lens mass, and theoretical understanding of the global properties of microlensing.

A major ''spin-off'' of the massive variability searches was implemented following the idea that detached eclipsing double line spectroscopic binaries can be used to measure distance directly. A visitor to Princeton, Dr. J. Kaluzny of the Warsaw University Observatory, successfully continued the search for such binaries in star clusters and in M31.

The OGLE data continued to be used for studies of the Galactic bar and the star distribution towards Baade's Window. Additional catalogues of variable stars discovered in the OGLE data were published. All photometric measurements of all these stars, and the finding charts are available electronically by ftp and WWW.

It is generally recognized that Kolmogoroff hydrodynamic turbulence is very effective in generating and amplifying magnetic fields, so it is important to understand the process by which it happens. On the basis of the MHD fluid equations it appears that magnetic energy is rapidly built up on very small scales, scales smaller even than the viscous scale of Kolmogoroff turbulence. If the resistivity η is much smaller than the kinematic viscosity ν, then the energy rapidly propagates all the way down to the resistivity scale which can be orders of magnitude smaller than the viscous scale. However, in general the mean free path is only moderately smaller than the viscous scale, and the plasma is effectively collisionless on scales smaller than the mean free path. Kulsrud, Cowley, Sudan and Gruzinov (1997) have shown that in the collisionless limit, even very weak magnetic fields rapidly damp any motions that would tend to amplify the magnetic fields. This is true provided the gyroradius is smaller than the mean free path. As a result, the generation of energy on smaller scales than the mean free path is effectively blocked and magnetic energy cannot reach smaller scales in a realistic plasma. This result is important for properly understanding the role of small-scale magnetic fields in astrophysical dynamos in plasmas for which $\eta \ll \nu$.

Magnetic reconnection is important in many astrophysical contexts such as in the sun and in accretion disks. Kulsrud and Ph.D. student Uzdensky are studying the infinitely large magnetic Reynolds number limit of two-dimensional magnetic reconnection. In this limit the geometry of the magnetic reconnection breaks up naturally into a narrow boundary layer in which the magnetic reconnection actually occurs and the surrounding global regions. As plasma reconnects it passes into a second narrow region that separates the unreconnected plasma and the reconnected plasma, the separatrix region. All the rest of the plasma is in magnetostatic equilibrium.

Uzdensky and Kulsrud (1997) show that it is important to understand the dynamics of the flow into this separatrix region because the back pressure from the deceleration of this flow in this region can react back on the main reconnection layer and slow down the magnetic process itself. Further, they have shown that The reconnection layer has to be connected to the separatrix region through a magnetic cusp by generalizing and correcting a previous theory of magnetic cusps carried out by Bekstein and Priest. The knowledge of the magnetic field and flows just outside of the narrow boundary layer regions is necessary to properly solve for the magnetic reconnection and flows in this region, and thus to determine the reconnection rate.

James Binney (Oxford), Ortwin Gerhard (Basel) and Spergel explored the photometric structure of the inner Galaxy. The light distribution in the inner few kiloparsecs of the Milky Way is recovered non-parametrically from a dust- corrected near-infrared COBE/DIRBE surface brightness map of the inner Galaxy. The best fits to the photometry are obtained when the Sun is assumed to lie $\sim 14 \pm 4$pc below the plane. The recovered density distributions clearly show an elongated three-dimensional bulge set in a highly non-axisymmetric disk. In the favored models, the bulge has axis ratios 1:0.6:0.4 and semi-major axis length ~ 2kpc. Its nearer long axis lies in the first quadrant. The bulge is surrounded by an elliptical disk that extends to ~ 2kpc on the minor axis and ~ 3.5kpc on the major axis. In all models, there is a local density minimum ~ 2.2 kpc down the minor axis. The subsequent maximum ~ 3 kpc down the minor axis (corresponding to $l \simeq -22°$ and $l \simeq 17°$) may be associated with the Lagrange point L_4. From this identification and the length of the bulge- bar, they infer a pattern speed $\Omega_b \simeq 60-70$kms kpc^{-1} for the bar. Experiments in which pseudo-data derived from models with spiral structure were deprojected under the assumption that the Galaxy is either eight fold or four-fold symmetric, indicate that the highly non-axisymmetric disks recovered from the COBE data could reflect spiral structure within the Milky Way if that structure involves density contrasts greater than >3 at NIR wavelengths. These experiments indicate that the angle ϕ_0 between the Sun-centre line and a major axis of the bulge lies near 20deg.

2.5 Instrumentation and Software

The second orbital flight of the Interstellar Medium Absorption Profile Spectrograph (IMAPS) occurred during a long-duration Shuttle mission (STS-80) in November and December of 1996. Once again, IMAPS was attached to the Astro-SPAS spacecraft which was flown on a mission sponsored by the US and German space agencies, NASA and DARA. IMAPS is an objective-grating echelle spectrograph that can record the spectra of bright, early-type stars in the wavelength interval $930-1150$Å at the high resolution that is needed to see most of the velocity structure in the absorption features. In an observing program that was divided equally between scientists on the IMAPS team and guest observers, the following stars were observed: γ Cas, ϵ Per, ξ Per, δ Ori, ϵ Ori, μ Col, β CMa, 15 Mon, ϵ CMa, HD 64760, ζ Pup, γ^2 Vel, α Leo, ρ Leo, η UMa, β Cen, and α Gru. Many interstellar species were detected, the most important of which included H_2, O VI, and atomic deuterium. Improvements in the data collection system implemented by Princeton engineers P. Zucchino and M. Reale enabled IMAPS to operate at much higher efficiency than before — as a result of this improvement and a longer observing time, IMAPS gathered roughly eight times as much data as that obtained on the earlier flight in 1993. Analysis of the data from this mission is currently in progress.

The Sloan Digital Sky Survey work at Princeton includes several major contributions to the software systems, which will automatically reduce the SDSS data as they are taken. The photometric pipeline reduces the data from the CCD drift-scan imaging camera; it corrects the data for defects, finds objects, measures them, incorporates photometric and position calibrations, combines the data in the five different SDSS filters for each object, and outputs reduced and calibrated images plus a large number of measured object parameters. The last major task, the deblending of overlapping images, is well along. The software has been extensively tested using simulated images. The development of this pipeline has been carried out by a group consisting of R. Lupton, M. Richmond, Ž. Ivezić, J. Gunn, M. Strauss, G. Knapp and T. Quinn (University of Washington). The code will run on current computers at a rate close to that at which the data are taken.

Strauss and Lupton, with R. DeSimone (undergraduate), are testing the spectroscopic pipeline, which is being written at the University of Chicago. Lupton has made many contributions to the data base and infrastructure. Richmond has worked extensively on the code to reduce the photometric calibration data. Knapp and J. Goldman (undergraduate) are working on estimating the Galactic reddening and extinction over the survey area. Strauss, Lupton and Gunn, with graduate students X. Fan and K. Nagamine have also worked on the criteria for the selection of objects (quasars, galaxies and brightest cluster galaxies) whose spectra are to be taken.

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