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Cosmic microwave background and dark matter

One of the main areas of research is the theory of cosmic microwave background (CMB) anisotropies and analysis of CMB data. Using the four year COBE data we were able to improve existing constraints on global shear and vorticity. We found that, in the flat case (which allows for greatest anisotropy), $(\omega/H)_0 < 10^{-7}$, where ω is the vorticity and H is the Hubble constant. This is two orders of magnitude lower than the tightest, previous constraint. We have defined a new set of statistics which quantify the amount of non-Gaussianity in small field cosmic microwave background maps. By looking at the distribution of power around rings in Fourier space, and at the correlations between adjacent rings, one can identify non-Gaussian features which are masked by large scale Gaussian fluctuations. This may be particularly useful for identifying unresolved localized sources and line-like discontinuities. Levin and collaborators devised a method to determine the global geometry of the universe through observations of patterns in the hot and cold spots of the CMB.

We have derived properties of the peaks (maxima) of the CMB anisotropies expected in flat and open CDM models. We present results for angular resolutions ranging from 5 arcmin to 20 arcmin (antenna FWHM), scales that are relevant for the MAP and COBRA/SAMBA space missions and the ground-based interferometer[1].

Accurate tests of the competing models of structure formation have been undertaken by Gawiser and Silk. We have demonstrated[2] that there is a robust inversion, enabling us to reconstruct the underlying matter fluctuation power spectrum over scales from tens to thousands of megaparsecs utilizing deep redshift surveys, which already probe the power spectrum to $\sim$ 200Mpc, and the complementary intermediate angle CMB experiments. It is feasible to invert the CMB data for each experiment and specified window functions, and reconstruct piecewise the underlying matter power spectrum, providing a unique handle on bias. The large-scale anisotropy is unique in probing causally disconnected regions of the universe. On the largest scales, the COBE data can be used to provide more stringent limits on non-trivial topologies than have been possible before. In a topologically closed universe, we are able to see photons from all over that volume. This is unlike the case without topology for which the photons we see travel along radial geodesics from a surface of last scattering. When we look at the CMB in a topologically compact universe, depending on the particular topology, this can lead to patterns in the sky and new statistics to decipher those patterns[3]. All the multiconnected spaces of interest break isotropy and most also destroy homogeneity. We have looked for such a possibility[4] in contributions to the dipole, quadrupole and higher multipoles by studying the 6 compact, flat topologies. Our results generalize earlier work on flat spaces[5,6,7] in which the universe is wrapped into a flat hypertorus.

Metcalf found that there is a second order effect that causes the average magnification of the CMB to be non-zero[8]. While this would not have a significant effect on CMB observations, fluctuations in the gravitational magnification can cause significant changes in the CMB power spectrum at small angular scales. Gravitational lensing must be taken into effect if we hope to measure cosmological parameters to a high degree of accuracy using CMB measurements. Lensing introduces non-Gaussian statistical properties into the CMB if they are not already there. Traditional means of detecting non-Gaussianity (n-point functions) are too strongly effected by cosmic variance to detect lensing.

It has been argued that the power spectrum of the anisotropic in the Cosmic Microwave Background may be effectively degenerate, namely that the observable spectrum does not determine a unique set of cosmological parameters. We demonstrate[9] that at small angular scales the degeneracy is broken by gravitational lensing: effectively degenerate spectra become distinguishable at $\ell \sim 3000$ because lensing causes their damping tails to fall at different rates with increasing ℓ. Forthcoming interferometer experiments should provide the means of measuring otherwise degenerate parameters at the $5 - 25\%$ level.

Galaxy formation and evolution

If the dark halo contained significant amounts of gas, cosmic-ray protons originating from the galactic disc would interact with it, yielding a γ-ray flux which CGRO would have observed. By using a diffusion model with correctly reproduces the radial distribution of cosmic-rays along the galactic plane, we infer an upper limit of $\sim$ 2 to 4% on the fraction of gas in diffuse form or in clouds[10].

Self-regulation of star formation in disks is controlled by two dimensionless parameters: the Toomre parameter for gravitational instability and the porosity of the interstellar medium to supernova remnant-heated gas. An interplay between these leads to expressions for the gas velocity dispersion, gas fraction, star formation rate and star formation efficiency in disks and to a possible explanation of the Tully-Fisher relation[11].

Using a formulation for the global star formation rate based on the theory of gravitational instability in a cold self-gravitating disk[12] developed for our own galaxy, we can compute the star formation rate in disk galaxies at early times, obtaining the star-forming history as a function of galaxy age. For example, the disk star formation model that is generic to reproducing the Milky way properties is proportional to disk rotation rate and hence to roughly R^{-1}. This means that disks form inside out. Thus at a lookback time of $\gtrsim 5$ Gyr, disks should appear to be substantially smaller than their nearby counterparts[13]. Another application is to chemical evolution at high redshift: the model predicts the abundances in protodisks, which are often identified with damped Lyman alpha absorption line systems, with gas column density comparable to the surface density in nearby stellar disks, and at lookback times that correspond to $\gtrsim 10$ Gyr. N. Prantzos and Silk studied the cosmological implications of star formation and chemical evolution in the Milky Way. They proposed an expression for the star formation rate in spiral galaxies and a model of chemical evolution with a minimal number of adjustable parameters. The model accounts for most relevant data in the Milky Way. By adopting our Galaxy as a prototype, they are able to derive cosmological implications for the comoving star formation rate, gas amount, gaseous abundances and supernovae rates as a function of redshift[14]. Emission lines in hydrogen can be used to measure the approximate redshift of the reionization of the universe. There is a rapid change in absorption at the reionization event, which can leave sharp features in the spectrum of the recombining hydrogen. We have calculated these signals based on numerical simulations of the ΛCDM cosmogony [15].

Squires, Hoffman, Zaroubi and Silk have developed a general method of deprojecting two-dimensional images, tailored for galaxy cluster observations in the optical, X-ray and radio (through the Sunyaev-Zel'dovich effect). The method consists of the application of the Fourier Slice Theorem to the general case where the axis of symmetry is not necessarily perpendicular to the line of sight, and is based on an extrapolation of the image Fourier transform into the so-called cone of ignorance. The application of the deprojection algorithm to upcoming SZ, X-ray and weak lensing projected mass images of clusters will serve to determine the structure of rich clusters, the value of H_0, and place constraints on the physics of the intracluster gas and its relation to the total mass distribution. The method was demonstrated using a simple analytic model for cluster dark matter and gas distributions, and is shown to provide a stable and unique reconstruction of the cluster 3D structure.

Balland, Schaeffer and Silk have studied galaxy collisions and strong tidal interactions, both at present and during the collapse phase of clusters, in order to determine galaxy morphology via induced star formation. From a semi-analytical study of tidal interactions based on the impulse approximation, a set of rules was inferred to define galaxy morphologies as a function of their formation redshift and the density of the environment both in the field and in clusters. Halos which survive merging are counted as a function of redshift from the Press & Schechter multiplicity function. The model reproduces the observed fractions of Hubble types and predicts the formation epochs of galaxies[16].

The best fit parameters of CDM-like power spectra, as inferred from a recent galaxy peculiar velocity data set, were utilized to calculate the CMB radiation angular power spectrum between $l \sim 300$ and $l \sim 1100$. The imprint of the local patch of the universe on the CMB as viewed by a distant observer was studied[17]. The Wiener reconstructed density map was convolved with the output of a Boltzmann equation code in order to construct a $10'$ FWHM smoothed CMB temperature map. The map covers a scale of about 90 arc-minutes in the $\Omega = 1$ case, and the effect is discussed of low Ω in flat and open universes. The relation between the phases in the density map and the CMB temperature $\Delta T/T$ maps has important implications for reconstructing the underlying density field from current and future CMB experiments.

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