Preface

Our ideas of the nature of the primordial universe have varied with time, closely following our understanding of physics. With Einstein and Hubble in the 1920s we learned from General Relativity that observing distant objects in the expanding universe was the key to unravelling our past. Primordial at that time meant the study of the past of a universe apparently younger than the Solar System, at an age of 1 billion years. This contradiction was only resolved in the 1950s as the modern distance scale became accepted. Gamow in the 1950s also understood the role of Nuclear Physics in the synthesis of the light elements during what we call now the Big Bang. Although it took a decade, until the discovery of the Cosmic Microwave Background Radiation, for Gamow's pioneering work to be recognised, these ideas provided theoretical as well as observational access to the primordial universe when it was only 3 min old, a big jump, undoubtedly. Sakharov in the 1960s told us why the universe was made of baryons despite the physics predictions of the existence of particles and antiparticles with similar properties.

The next step was to understand, thanks to Kirshnitz and Linde, that the particle physics motivated unification of the weak and electromagnetic interactions (now well established) implied a phase transition in the early universe, when it was barely 10^{-10} s old, with, at earlier times, much simpler laws of physics that were fundamentally different from those that presently hold. Also, Guth conjectured in the early 1980s that there was another major phase change when the strong interactions unified with the electroweak interactions, at an age of 10^{-40} s. The triggering of inflation explains the size of our present universe, which is a factor 10^{40} larger than the microphysics scale. Before this era, all particles would be massless and all interactions (but gravity) the same, within a perfectly symmetric universe! At these scales, however, the predictions of particle physics are far from being confirmed by accelerator experiments: so it became customary for cosmologists to invent for convenience their own laws of Physics, often differing from those particle physicists were devising separately!

Another major problem of Physics and Cosmology is the composition of the Universe. We know, as Zwicky discovered from the dynamics of the Coma cluster nearly 60 years ago, that the luminous matter generates only 1% of the gravitational field that is observed. Astonishingly, this dark matter seems to follow rather closely the irregularities in the distribution of the luminous matter. This dark matter cannot be in the form of star-like dark objects, as shown by the EROS and MACHO microlensing surveys, and primordial nucleosynthesis shows that only a small fraction can be in the form of baryons. The only sensible hypothesis is that there exists another, yet unknown, massive particle, in addition to the baryons, in large amounts, which is responsible for the observed missing mass.

In this School, the Primordial Universe is understood as the period from the electroweak unification up to the remotest epoch that is accessible to our knowledge. It reviews the achievements of the last decade, together with the latest new topics.

S. Lilly tells us about the present universe, what is observed, how one can describe it simply and about the explorations at high redshift. We now have a serious hint from our recent past, where galaxies are seen to evolve strongly with intense star formation. J. Silk gives us the latest values of the cosmological parameters; we now know the value of the Hubble constant to within 10%. K. Olive, in a short review of Primordial Nucleosynthesis, shows the recent, rather puzzling, abundance measurements to be no longer a burden. F. Bouchet, J.L. Puget and J.M. Lamarre review the microwave background fluctuation measurements. The prospects from the MAP and PLANCK satellites are impressive. We will know everything about primordial fluctuations: the shape of the spectrum, the geometry of space after recombination, and the baryon fraction. Balloon-borne flights, however, are now starting to be challenging competitors. They just told us that our universe is flat! Along the path opened by COBE, this gives observational access to the epoch when the universe was no more than 10^{-40} s old, undoubtedly a bridge towards the microphysics that determined our origins.

The microphysics relevant for cosmology is reviewed in the major part of these lectures. The good news is that fashions change: the idea now is to use the laws of physics that are thought to be realistic by particle physicists rather than those that turn out to be convenient for cosmology. This is a difficult task. K. Olive reminds us about the basic ideas behind the Supersymmetric Theories. The new particles predicted by these theories are expected to be at the origin of the observed dark matter. Searches are underway to detect these particles. As shown by G. Chardin the detectors are now at the limit of reaching the required sensitivity considering the expected interaction rates.

The desires of cosmologists, confronted with the requirements of particle physics to explain the evolution of the Universe during inflation, the creation of matter soon afterwards, and the appearance of quantum fluctuations, very likely at the origin of the gravitational structures we see today, are reviewed by A. Linde. The observations allow the cosmological constant found in the supernova surveys to vary slowly with epoch. This is predicted by some theories based on supersymmetry. This component is then to be interpreted as a new kind of matter that has been given the name "Quintessence". P. Binétruy reviews the state of the art. R. Kallosh, in another timely illustration, emphasizes the very special cosmological role of the gravitino. N. Turok discusses the defects that may appear during the various phase transitions which occur in the early universe, and the associated astrophysical constraints. The electroweak transition now appears to be too smooth to be responsible for the origin of the baryon asymmetry, at variance with the standard working hypothesis of the last decade. As a start to the third part of the course, N. Turok also tells us his views about what happened right after the Planck era.

The final courses deal with the Planck era, just after, or just before. Superstrings and M-Theory are the natural extension of the Supersymmetric theories, including gravity. T. Banks provides us with quite an appealing introduction to these matters. From the symmetry between positive and negative times that holds in superstring theory, G. Veneziano shows us the how post- and pre-Big Bang eras are related.

Cosmology and particle physics meet again. They have never been very far apart in the last 20 years, but the ties were never so close. Clearly, the constraints of particle physics on cosmological scenarios are severe, but the reverse also holds: not all theories of the elementary particle interactions survive when they are required to explain our origins. The major issue is still to unravel the nature of dark matter, which possibly appears in the form of several, fundamentally different, components. Also, we still do not understand how the baryon asymmetry built up in our Universe. The most modern theories that unify all fundamental interaction, still awaiting experimental confirmation, now give us a hint as to what conditions were prevailing not only at the Planck era, but even before the start of the Big Bang. Undoubtedly, finding out how these old problems and these new ideas are entangled will be the challenge of the next decade.

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