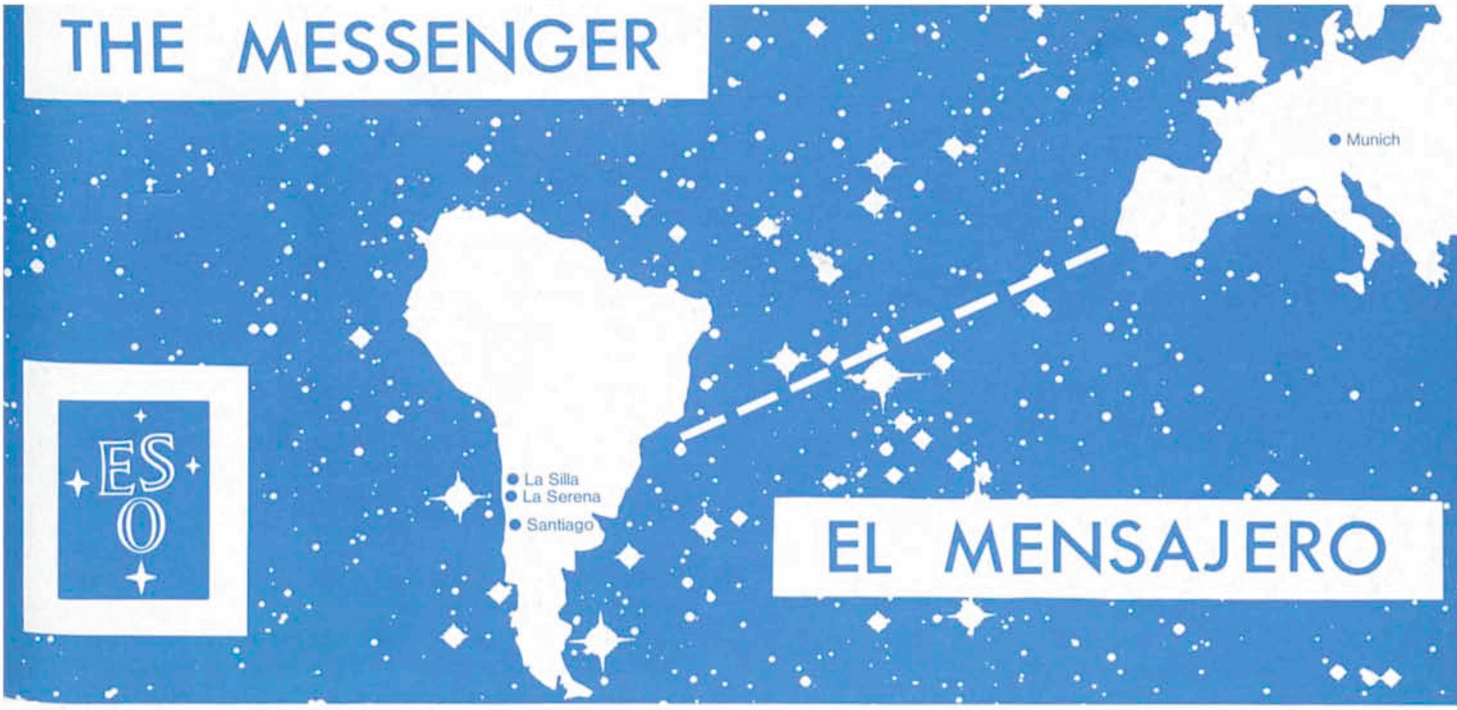

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Report on the First ESO-CERN Symposium on "Large Scale Structure of the Universe, Cosmology and Fundamental Physics"

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The first ESO-CERN Symposium was held at CERN, Geneva, from 21st to 25th November 1983 and was attended by approximately 200 participants. The discussions concentrated on the general field of Cosmology, where the progress made in the past twenty years, both in elementary particles and astronomy, has shown that these two fields of basic research are merging toward a new and fundamental understanding of the laws that govern our Universe. A detailed account is contained in the Proceedings of the Symposium which will be available in a few months.

The meeting was started with an introductory lecture by D. W. Sciama (Oxford and Trieste) who highlighted the numerous and fundamental problems the understanding of which appears to require a joint effort of particle physicists, astrophysicists and cosmologists.

As discussed by L. Woltjer (ESO), the astronomical observations have shown that the Universe is not only expanding, but also strongly evolving in the sense that the physical properties of the galaxies have changed with time. For instance, it has been discovered that certain classes of objects, such as radio galaxies and quasars, were more numerous and probably more powerful in the past than they are now. This, together with the discovery of the properties of the so-called universal background radiation, has led to the conclusion that the Universe can be described by the most simple homogeneous and isotropic models of General Relativity, whereby it has evolved from a very condensed and very hot phase about 20 billion years ago—the "hot big-bang". This interpretation has an additional attraction: it can explain in a very natural way the abundances of certain elements, which would be extremely difficult to account for by the nuclear processes taking place in stars. Accordingly, the bulk of elements, such as helium and deuterium, were produced when the age of the Universe was only about 100 seconds, the temperature about one billion degrees and the density of the order of the density of water, in a phase that lasted about 8 minutes. At that moment the Universe was essentially a gaseous mixture composed of protons, neutrons, electrons, positrons, neutrinos and antineutrinos (and perhaps some other exotic particles, such as photinos) immersed in a heat bath of photons. The equilibrium between these components is maintained by the weak interaction, one of the four fundamental forces which are believed to govern all natural phenomena.* The weak force together with the "hot big-bang" model allows definite predictions about the abundances of primordial elements. As pointed out by J. Audouze (Paris), this astrophysics model limits the number of neutrino types to no more than 4, which is already significantly better than the upper limit of about twenty obtained in particle physics experiments (data on Z° decay obtained at CERN). Another important constraint that stems from primordial element abundances is that the present

* The four fundamental forces are: the *electromagnetic force*, which acts among electrically charged particles and is transmitted by the photon (it governs the structure of the atom); the *weak force*, which acts on leptons and hadrons and is transmitted by the bosons W^+, W^-, Z° (it is responsible for the beta decay of radioactive elements); the *strong force*, which acts on hadrons and is transmitted by particles called pions and kaons (it is responsible for the nuclear forces that keep together the protons and neutrons in the atomic nuclei; the strong interaction among the quarks, which are supposed to be the constituents of the protons and neutrons, is due to particles called gluons); and the *gravitational force*, which acts on everything and is transmitted by a particle called graviton.

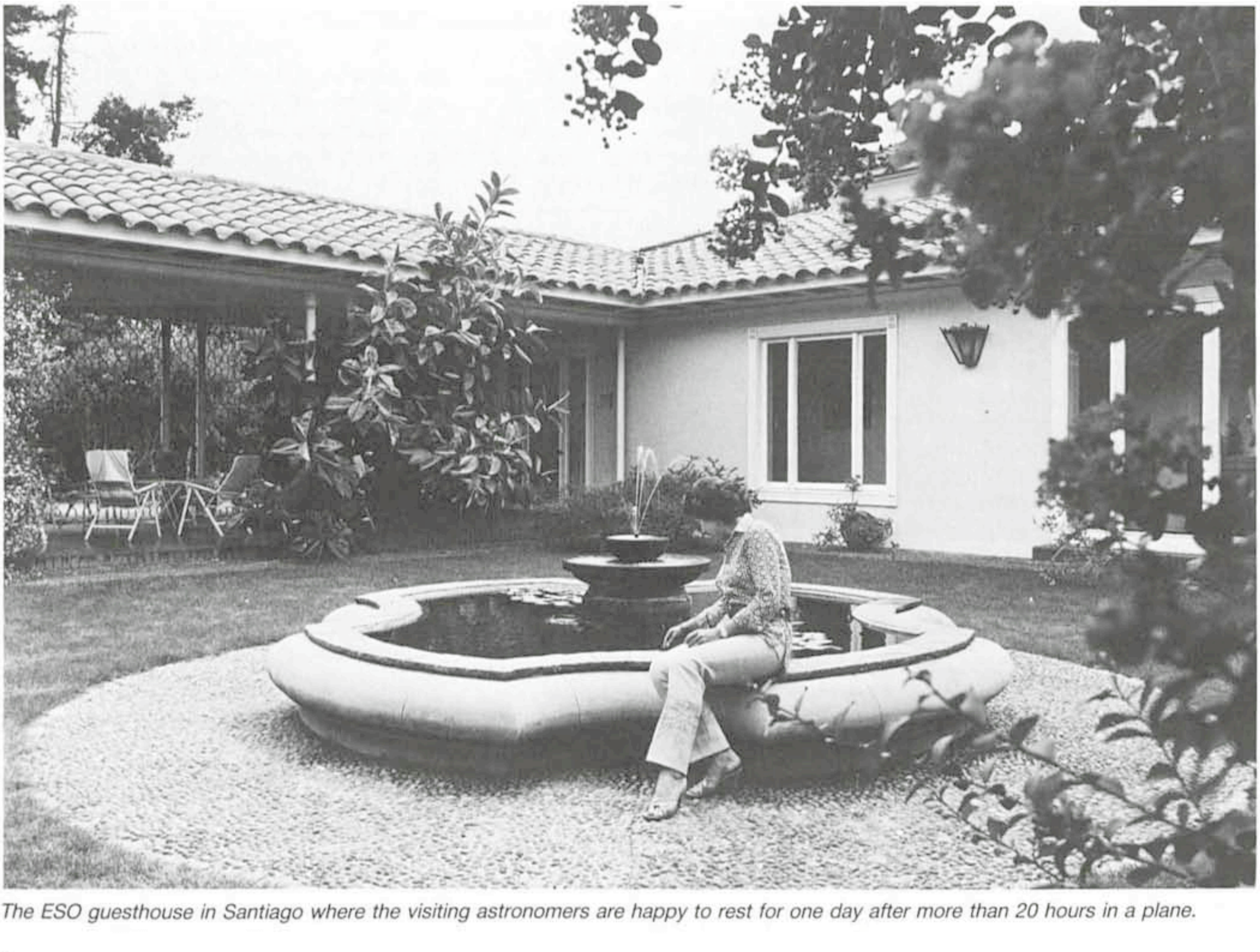
[The leptons include the electron, the muon and the tau particles and the three corresponding types of neutrinos. The hadrons include the baryons (which ultimately decay into protons) and the mesons.]

density of baryonic matter in the Universe cannot be more than about 10% of the "closure" density, that is to say, the density which divides the model universes derived from general relativity into "open" and "closed". If the density is less than the closure density then the Universe is "open" and will expand forever to infinity or, vice-versa, it will reach a maximum size at some time in the future and will then recollapse under the action of its own gravity. In principle, it should be possible, by means of astronomical observations, to find out in what kind of universe we live. In practice, however, this entails the use of a class of astronomical objects (such as galaxies of a certain type) which should be bright enough to permit a mapping of the Universe in depth and whose intrinsic properties do not change with the cosmic time. As discussed by A. Sandage (Pasadena), despite great efforts it has not yet been possible to separate the evolutionary effects from those due to the geometry of the Universe. The solution to this fundamental problem has probably to await the advent of both the Space Telescope and the large telescopes of the future, such as the VLT.

That most of the matter in the Universe may indeed be in non-luminous form has been convincingly argued by S. Faber (Lick Observatory) on the basis of observations of different types of galaxies, groups and clusters of galaxies. It appears as though in these different types of astronomical conditions ordinary visible matter makes up only about 10% of the total mass involved. The nature of this "dark" matter has been the subject of many speculations and everything, from certain types of elementary particles, to mini black-holes, up to very massive stars with a mass of about one million times the mass of the Sun, has been proposed. To illustrate how unsatisfactory the situation is, it suffices to remark that the masses involved in these different proposals extend over a range of at least *seventy* orders of magnitude!

A very important theoretical development has taken place in the past few years with the application of the concepts of grand unified theories of physics (GUTs) to cosmology. To highlight this let us first briefly summarize some of the basic problems facing the cosmologists.

Strangely enough, the first problem comes about because the Universe looks so isotropic. Observations of galaxies and extragalactic radio sources (radio galaxies and quasars) show that the distribution of condensed matter in space, aside from local irregularities, is isotropic to better than one part in a hundred. But a much stricter limit is derived from the observations of the 3°K universal radiation which, as reported by D.T. Wilkinson (Princeton), appears to be intrinsically isotropic on all angular scales to better than one part in ten thousand. However, in the framework of the standard "hot big-bang" model it can be shown that two hypothetical observers placed, say, 180° apart in the sky at a distance corresponding to the last moment in which the universal radiation interacted with ordinary matter, could not have communicated with each other. Technically speaking, this is equivalent to saying that the "horizons" of the two observers, whose radii increase with the speed of light (the maximum possible speed), were still well separated. Now the isotropy problem arises because it is difficult to see how regions of space which had no time from



The ESO guesthouse in Santiago where the visiting astronomers are happy to rest for one day after more than 20 hours in a plane.

the moment of the original explosion to come into physical interaction can look so similar, as indicated by the isotropy measurements mentioned above.

The second problem, which in technical terms is known as the "flatness" problem, is directly related to the density of matter in the Universe. It arises from the simple observation that any deviation of the matter density from the "closure" density increases with cosmic time. Thus, if the present density of the Universe is only about 10% of the closure density—as indicated by observations of the content of baryonic matter—at the time when the Universe was only about 100 seconds old (or when the compression factor was ~ 10 billion), the density of matter deviated from the closure density only by one part in one hundred thousand. Most researchers consider this fine-tuning very unnatural and, consequently, believe that the matter density must have always been very close to the "closure" density.

The third problem is concerned with the apparent asymmetry in the matter/anti-matter content of the Universe, that is to say, with the evidence that the Universe is essentially composed of baryons. In the simple standard "hot big-bang" model, there is no reason to think that initially at least the Universe was not highly symmetric, with equal numbers of baryons and anti-baryons in equilibrium with the radiation field: baryons and anti-baryons annihilate into photons and, vice-versa, photons materialize into baryon/anti-baryon pairs. Because of the cooling due to the expansion of the Universe, eventually all baryon/anti-baryon pairs annihilated giving rise to a corresponding number of photons that constitute the universal radiation field now observed at a temperature of 3°K, but somehow a small amount of baryons was left over. That the deviation from a perfect baryon/anti-baryon symmetry should have been small is shown by the fact that presently there are about 100 million photons per baryon (the universal radiation has cooled down to its present temperature of about 3°K because of the expansion of the Universe, but the number of photons has been conserved). If the Universe was baryon symmetric to start with, the above picture of course implies that the baryon number has not been strictly conserved (it should be remembered that a baryon and an anti-baryon add exactly in the opposite way, giving a total baryon number identically equal to zero).

Recent developments in elementary particle physics and fundamental theory, when applied to cosmology, may in fact indicate an elegant way out of these problems. After the successful confirmation of the Glashow, Salam and Weinberg theory on the unification of electromagnetic and weak forces recently obtained at CERN with the discovery of the W^+ and Z° bosons, as discussed by P. Darriulat (CERN), there is now an increased confidence in the theoretical approach to the unification of all fundamental forces. It should be noted that almost a century has elapsed since Maxwell made the first fundamental step of incorporating electric and magnetic forces into one unified scheme—the theory of electromagnetism. As reviewed by P. Fayet (Paris), there are a number of theoretical models which have been proposed to unify the electro-weak and strong interactions, generally known as Grand Unified Theories (GUTs). At this moment, it still appears difficult to work out definite quantitative predictions, but one quantity which seems to be fairly well estimated is the energy of the particles above which the models should become exact, that is to say, the unification energy at which the forces lose their individuality. This energy turns out to be about 10^{14} GeV, which corresponds to a mass which is about 10^{12} times the mass of the W^+ and Z° bosons. This means, of course, that a direct verification of the GUTs via the production of the particles which mediate the unified force is unthinkable, except in the too distant future. However, in the "hot big-bang" picture, these extremely high energies are reached naturally at the very beginning of the life history of the Universe, when its age was less than about 10^{-35} seconds. After this time, the cooling due to the expansion of the Universe brings the average energy of the particles below 10^{14} GeV.

One of the predictions of GUTs is that the proton should decay with a half-life in the range 10^{31}–10^{33} years, very much greater than the age of the Universe (~ 2 x 10^{10} years). This possibility arises because in the GUTs the quarks, which are the constituents of the baryons, and the leptons are parts of the same picture. As a consequence, the baryonic number need not be conserved any more, as had been assumed in the classical models of elementary particle theory. The results of a number of experiments set up to measure the proton half-life were reviewed by E. Fiorini (Milan). The most stringent result is now being obtained from the Ohio Morton Salt mine experiment which sets a lower limit to the proton half-life of 1.5 x 10^{32} years. This result already enables one to rule out the simplest of the GUT models which predicts that the proton half-life would be at most 10^{31} years.

Because of the non-conservation of the baryonic number, one can work out a scheme which leads in the first 10^{-35} seconds to a baryon asymmetric universe, even if one had started from conditions of perfect symmetry between particles and anti-particles, in this way explaining one of the basic cosmological problems outlined before. Unfortunately, it is not yet possible, within the framework of GUTs, to make a quantitatively precise estimate of the excess of matter over anti-matter.

In a related context, G. Giacomelli (Bologna) reviewed the present status of the search for monopoles, the magnetic counterparts of the electric charge, whose existence is predicted by the GUT's schemes. Since their mass is enormous (~ 10^{15} GeV), they cannot be produced in the laboratory, but of course might have been produced in the very early phases of the "hot big-bang" and now pervade the Universe. In fact, the production might have been so copious that one has to invoke "suppression" schemes to avoid conflict with the upper limit on their present space density.

Another important feature of the more elaborate GUTs is the expectation that neutrinos have non-zero rest mass. Obviously, this immediately raises the possibility that "dark" matter, which may pervade the Universe as previously discussed, is provided by the neutrino sea. In the standard "hot big-bang" model one can compute, in a fairly accurate way, the number density of neutrinos which turns out to be of the same order as the photon density in the 3°K universal radiation field, that is

Tentative Time-table of Council Sessions and Committee Meetings in 1984

April 13	Scientific Technical Committee
May 22	Users Committee
May 23	Finance Committee
June 4–5	Observing Programmes Committee
June 6	Committee of Council, Geneva
June 7	Council, Geneva
October 8	Scientific Technical Committee, Chile
November 13–14	Finance Committee
November 27–28	Observing Programmes Committee
November 28	Committee of Council
November 29–30	Council

All meetings will take place at ESO in Garching unless stated otherwise.

to say, about 100 million, or so, per cubic metre. With this kind of density a very small mass of neutrinos, corresponding to a rest-mass energy of a few tens of an electron volt, is already sufficient to provide the "closure" density of the Universe. However, there appear to be difficulties with this kind of picture. Calculations which simulate the non-linear growth of structures in the expanding Universe can be compared with the observed distribution of galaxies which, as discussed in detail by J. H. Oort, appear to cluster on the large scale in configurations (superclusters) whose sizes are typically 150 million light-years. In a universe dominated by massive neutrinos, the characteristic scale on which matter condensations can form and collapse is clearly controlled by the maximum distance neutrinos can travel before they are cooled down, due to the expansion of the universe. As pointed out by J. Silk (Berkeley), this distance is too large and apparently leads to a typical size which by far exceeds the observed clustering scale of galaxies. Consequently, if the standard cosmological parameters hold, one would have to conclude that neutrinos cannot provide the missing mass in the Universe. Clearly, the solution to all these problems depends, in the end, on a direct measurement of the neutrino mass. According to R. L. Mössbauer (Munich), who reviewed the experimental situation for the measurements of the masses of the various kinds of neutrinos, the most recent result of an experiment carried out in the Soviet Union indicates that the rest-mass energy of the electron neutrino should be at least 20 eV. This result is clearly of crucial importance and one hopes that other experiments will soon allow to verify its validity.

An important development in theoretical cosmology, which would in fact provide a solution to the isotropy and flatness problems discussed earlier, has recently been proposed by Guth in the framework of GUTs. After the first 10^{-35} seconds, the cooling due to the expansion of the Universe would bring the thermal energy below the grand unification energy of 10^{14} GeV, the electro-weak and the strong forces would again acquire their identity and one would expect something to happen at the transition time (more technically one expects a decrease in the symmetry properties of the fields). Guth's basic idea is that essentially nothing happens for a while: the Universe expands and cools down by many factors of ten, while certain properties of the system remain, so to say, "frozen". The system lives for a while in an "excited" state which would drive the expansion in such a way as to enable an effective exchange of information through the Universe. Essentially, a very small piece of the Universe, which is causally connected in the initial phase of this expansion where, roughly speaking, the expansion velocity is less than the velocity of light, is then stretched by a very large factor (of the order of 10^{44}), and from this piece our entire Universe is made. At the same time, this would lead to a model universe in which the density is *almost exactly* the closure density. When the system makes the transition to its "normal" state, the energy which had been "frozen" in the fields is suddenly released and the Universe is reheated to a thermal energy of approximately 10^{14} GeV, and the considerations we outlined before apply again. It is as if the Universe was born anew. These types of theoretical schemes are known as inflationary models. As discussed by D. Nanopoulos (CERN), however, there are still a number of difficulties concerned with a fuller understanding of the basic physics at work and, in particular, the most recent investigations lead to models that are affected by inhomogeneities which appear to be so large that their presence would contradict what can be allowed in the real Universe. However, the basic idea of "inflation" is extremely appealing and one other possibility is that it can be applied to even earlier times, when the Universe was only 10^{-43} seconds old. This time, known as the Planck time, corresponds to a thermal energy of approximately 10^{19} GeV above which all four fundamental forces of nature are unified, including gravity. The basic physics prevailing at that moment may be correctly described by the so-called supersymmetric theories, such as "supergravity". The most remarkable property of these theories, as reviewed by Fayet, is that they correlate particles with adjacent spins, such as particles with spin 1 and spin ½, and therefore bring together bosons (such as the photon) and fermions (such as the electron and the proton). The existence of a number of new particles is then predicted. Thus, in "supergravity", which originates from supersymmetry by assuming that its properties are locally invariant, one recovers not only the graviton, which is the spin 2 particle which mediates the gravitational field in general relativity, but also a spin 3/2 particle called the gravitino. Thus, the partner of the photon would be a new spin 1/2 particle called photino. These new particles, the ". . . ino"s, could play an important role in cosmology and, if massive, they could provide the missing mass needed to close the Universe, avoiding some of the problems associated with neutrinos as previously illustrated.

Clearly, supersymmetric theories are still highly speculative and there is, as yet, no experimental verification of their validity. However, it is interesting to note that astronomical observations could shed some light on the existence of the new particles that are predicted. For instance, Sciama has pointed out that the annihilation of photinos and anti-photinos, if they are indeed massive enough, could produce a large background flux of radiation detectable by far ultraviolet and soft X-ray measurements.

Thus the Universe appears to provide the "natural" laboratory where one can hope to test fundamental theories of physics, while, at the same time, any progress in experimental particle physics may increase our confidence that these theories can be applied to an understanding of the basic

SECOND ANNOUNCEMENT
OF AN ESO WORKSHOP ON

THE VIRGO CLUSTER OF GALAXIES

Since the first announcement of this workshop was issued in the previous Messenger (No. 34, December 1983) the date has been fixed and a preliminary programme made. The workshop will be held in **Garching,** from **September 4–7, 1984.**

The programme covers the following topics: Redshifts, observations in the radio continuum and in H I, infrared observations (with special emphasis on IRAS results), optical spectroscopy, spiral pattern analysis, galactic content and structure, the population of dwarf galaxies, UV and X-ray observation, the cluster dynamics, and the interaction with the environment.

Among the invited speakers are: W. Forman, W. K. Huchtmeier, J. Huchra, R. C. Kennicutt, C. Kotanyi, A. Sandage, G. A. Tammann and R. B. Tully.

Those interested in participating in this workshop and/or presenting contributed papers (probably mostly in the form of poster papers) should write to:

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cosmological problems. Admittedly, we are still at the beginning of the road, but the interplay between particle physics and cosmology may indeed lead us to a deeper understanding of the fundamental laws of nature.

A most remarkable paper was presented by S. W. Hawking (Cambridge) who showed that, under certain plausible assumptions, the Universe may be described by a wave function obeying a simple Schrödinger equation such that the most probable state would correspond to an oscillating model universe, singularity free, which is initially inflating and where the entropy does not change with time.

The Symposium ended with two concluding lectures by M. J. Rees (Cambridge) and J. Ellis (CERN) respectively, who summarized beautifully the main items discussed during the meeting and set the perspective for future work from the astrophysicist's and particle physicist's standpoint.

Chromospheric Emission, Rotation and X-ray Coronae of Late-type Stars

R. Pallavicini, Arcetri Astrophysical Observatory, Florence, Italy

In a short note which appeared in 1913 in the *Astrophysical Journal*, G. Eberhard and K. Schwarzschild reported on the observation of emission reversals at the centre of K line of Ca II in some bright late-type stars (Arcturus, Aldebaran, σ Gem). They also noticed that the same phenomenon is usually observed in active regions on the Sun. To my knowledge, this was the first time that chromospheric emission was reported from stars other than the Sun. Since those early days our knowledge of stellar chromospheres has enormously increased, mainly through systematic surveys in the H and K lines of Ca II. More recently, observations at UV and X-ray wavelengths from space have provided ample evidence that chromospheres, transition regions and coronae are common to stars throughout the HR diagram. What is more significant is that these observations have demonstrated that magnetic fields play a fundamental role in the heating of outer stellar atmospheres and that the observed emission levels are in strong qualitative and quantitative disagreement with the predictions of the standard theory of coronal formation via the generation and dissipation of acoustic waves. The emphasis at present is on heating mechanisms which are based on the stressing and dissipation of magnetic fields generated by dynamo action in subphotospheric convection zones. As a result of this, stellar rotation has come to play a central role in the heating problem, as a controlling factor of the efficiency of the dynamo process. It can be anticipated that in the near future new accurate determinations of stellar rotation rates, as well as new measurements of transition regions and coronal emission from space will substantially increase our understanding of the process of coronal magnetic heating in late-type stars.

Chromospheric and Coronal Heating

In the solar atmosphere, the temperature, after decreasing outwards to a minimum value of $\simeq$ 4,500 K in the upper photosphere, starts to rise again, reaching 10^4 K in the chromosphere and more than one million degrees in the corona. Since heat cannot flow from lower to higher temperature regions (second law of thermodynamics) the observed temperature rise requires a non-thermal energy flux to be added to the thermal flux generated by thermonuclear reactions in the core of the Sun and flowing outwards under the form of radiation and convection. For stars of spectral type later than early F—stars which are known on theoretical grounds to possess outer convection zones—the required energy flux has been traditionally ascribed to the generation of acoustic waves by turbulent motions in the convection zone. These waves, propagating in an atmosphere of rapidly decreasing density, steepen into shocks and dissipate their kinetic energy into thermal energy, thus producing the observed temperature rise.

In its simplest formulation this theory, first suggested by L. Biermann and M. Schwarzschild in the late forties and since then universally accepted, neglects the presence of magnetic fields which are considered as an unnecessary, easily avoidable, complication. Consequently, generation of acoustic waves and heating of outer stellar atmospheres are supposed to be spatially homogeneous and temporally constant, at variance with spatially resolved observations of the Sun, which show the chromosphere and corona to be both highly structured and time variable. For example, Fig. 1 shows a spectroheliogram of the Sun obtained in the K line of Ca II. Enhanced chromospheric emission is observed from magnetically disturbed active regions ("plages"), as well as from the

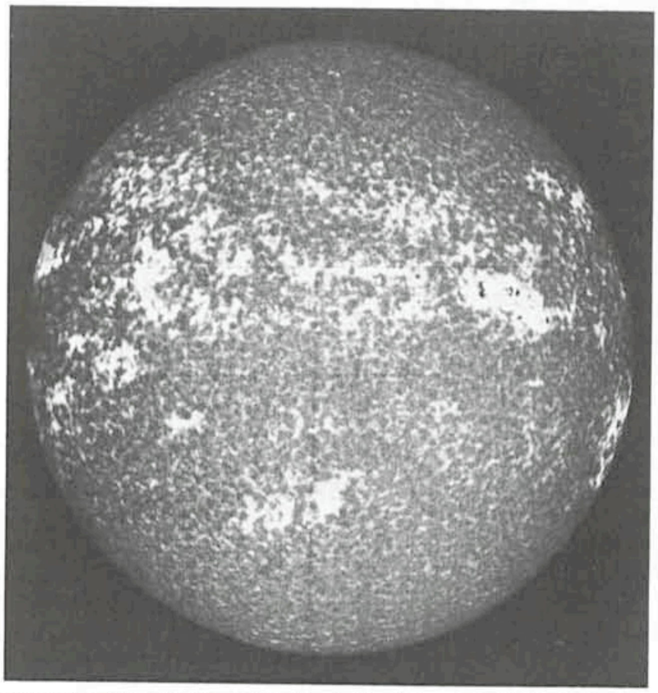

Fig. 1: *Spectroheliogram of the Sun in the K line of Ca II obtained at the Solar Tower of the Arcetri Observatory. Notice the enhanced emission from the chromospheric network and from magnetically disturbed active regions.*