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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS

ASTRO-PARTICLE-PHYSICS

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The ide[illegible] holding Marcel Grossmann meetings was an inspired invention of Remo Ruf[illegible]. I well remember the autumn of 1974 when Remo came to my office in Trieste and proposed our holding a meeting "for reviewing advances in gravitation, plus general relativity and ideas of space-time structure".

The first meeting was held at the International Centre for Theoretical Physics in Trieste in July 1975; the second also in Trieste in July 1979; the third in September 1982 in Shanghai. This is the fourth meeting in the series - the first in Remo's own habitat - if indeed he has one habitat!

To keep with traditions set up in Trieste and Shanghai, the main topics covered in this meeting are: (1) gravitational waves (Amaldi, Weber, Fairbank, Drever), (2) gravitational lens effect, (3) tests of general relativity, particularly the gyroscope test, (4) news of the space telescope, with its two metre mirror planned for 1986 and of space stations, in preparation for 1990, and (5) micro-wave background (isotropy $\frac{\Delta T}{T} < 10^{-5}$.

This range of subjects is classical cosmology at its highest. However, this particular meeting will be much concerned with the symbiosis of cosmology and particle physics. This has reached such a stage that when I consulted de Rujula of CERN - who is due to give the closing summary at the forthcoming European High Energy Physics Conference scheduled for Bari next month, on what the greatest advances in particle physics were, he said: All advances I shall report on were inspired by cosmology. Some of these are:

1.The number of light neutrino species can now be inferred from Z^o width at CERN; this appears to be 4.5 (+ 3.8 $\pm$ .9). One may recall that this number (N_ν 4) is very close to the cosmological prediction made some time ago. I am reminded of Landau's famous remark: "Cosmologists are often wrong, but seldom in doubt". We will have to change Landau's dictum now, to say: "Cosmologists can even be demonstrably right".

2.An important experiment to be discussed at Bari will concern gamma rays from

CYG X-3. These have been detected by (some - not all) experiments set up for detecting proton decay. The detection of hard γ-rays appears to imply that there are cosmic accelerators which are producing energies of the order of 10^4 TeV. This would appear to be the highest available energy for particle phenomena registered so far - 10^4 times higher than any that can be produced by terrestrial accelerators at present. According to the London Economist, any day, particle physicists will be asking astronomers if they can borrow their telescopes to test their theories!

Why are we in particle physics interested in cosmology?

On the experimental side, we have come to realise that even with a hadron collider in the LEP tunnel at CERN ($\gtrsim$ 10 TeV) and the SSC accelerator ($\gtrsim$ 40 TeV) which may be commissioned in the USA during the 1990's, we will be far, far from reaching (the ultimate) Planck energies of $\approx 10^{16}$ TeV.

Our present hopes for obtaining higher energies through future accelerators are centred on laser-plasma beat wave accelerators which promise to deliver 1000 times higher energies for the same length of accelerator as to-day.

But even with such techniques available, an accelerator like the one anticipated by Fermi, circling the earth would deliver no more than 10^7 TeV: an accelerator extending from the earth to the sun will deliver no more than 10^{11} TeV. To obtain 10^{16} TeV, the new plasma-laser beat-wave accelerator would have to be 100 light years in length! No wonder then that since energies of the order of 10^{16} TeV were available in the Early Universe, we are all beginning to think of cosmology as the future for higher, indirect (or even direct) experimentation in particle physics (cf. Cgn X 3).

In the same vein, experiments on the surface of the moon may be needed in order to establish proton decay. As you are aware, proton decay experiments on earth, are riddled with the difficulty of neutrino backgrounds. These neutrinos are the ones which are produced by products of collisions of primary cosmic rays with the earth's atmosphere. The moon will provide an environment with no atmosphere and thus no neutrino background of this type. So one may consider transporting detection material and placing it in position inside the caverns on the moon. In an environment with no neutrino background, even one proton decay event is likely to be significant.

In this context, it is well to remember that the gravity waves - so hard to detect to-day - could well become routine tools of the 21st century high energy physics - providing new windows on Nature.

So much for experiment - consider theory now.

I. Since the 1970's, early cosmology has been dominated by particle-physics ideas of phase transitions associated with the unification of fundamental forces. Thus the manifestion of the phase transitions which signaled the spontaneous breaking of the electroweak force to the two distinct forces of electromagnetism and the weak-nuclear force, took place when the Universe was 10^{-12} seconds old, at a critical temperature of around 300 GeV. In this picture, as the Universe expands, it cools and goes through a relevant critical temperature. The symmetry is lowered spontaneously and a state of order created. This is what happened for the electroweak symmetry. Another (earlier) phase change, even more significant for cosmology, was the phase change associated with GUT breaking, which was signalled by proton decay and which presumably took place when the Universe was 10^{15} GeV hot in temperature. Still earlier was, presumably, the phase change associated with inflation.

II. Now in any gauge theory these phase transitions are accompanied by the creation of topological defects. These are highly relevant to cosmology. Some of these defects are (1) domain walls associated with the homotopy group π_0; (2) strings associated with π_1 and (3) monopoles associated with π_2. As is well known, the existence of domain walls, or of a large number of monopoles would spell disaster and contradict some of our

present cosmological ideas, while strings are highly desirable, as nuclei of galaxies.

On the one side of the coin, this type of agreement restricts the type of GUT theory and its spontaneous breaking. On the other side, it restricts the cosmological evolution which should theoretically be contemplated.

III. A "second" gift of particle physics to cosmology has been dark matter. In Table I are indicated the varieties of possible particles which particle physicists can offer in this context. You choose!

TABLE I

Possible Sources of Dark Matter	Mass	Possible Epoch of Origin
Invisible Axion	10^{-5} ev	10^{-30} sec (10^{12} GeV)
ν (neutrinos)	30 ev	1 sec (1 MeV)
Light { $\tilde{\gamma}$ $\tilde{g}$, } Supersymmetric Particles	KeV	10^{-4} sec (100 MeV)
Heavy { $\tilde{\gamma}$ $\tilde{g}$, } Supersymmetric Particles	GeV	10^{-4} sec
Heavy axions, sneutrinos $\tilde{\nu}$	GeV	10^{-4} sec
Monopoles	10^{16} GeV	10^{-34} sec (10^{14} GeV)
Kaluza-Klein Particles (Maximons, Pyrgons)	10^{18}-10^{19} GeV	10^{-43} sec (10^{19} GeV)
Quark Nuggets	10^{15} Grams	10^{-5} sec (300 MeV)
Primordial Black Holes	$\gtrsim 10^{15}$ Grams	$\gtrsim 10^{-12}$ sec ($\lesssim 10^3$ GeV)

IV. A third "gift" has been the possible existence of higher dimensions - the best indication of which will be the cosmological measurement of time variation of the fine structure constant $(\dot{\alpha}/\alpha)$ and of the gravitational constant $(\dot{G}/G)$.

V. But perhaps the most important news for this conference, so far as astro-particle physics is concerned, is the news of the emergence of a String Theory of Everything (TOE) - a theory which will embrace cosmology, all forces of Nature, including gravitation and all matter. A field theory of closed strings, of the size of Planck loops (10^{-33} cms.) is likely to replace point-field theory - a real revolution. Witten has remarked that the next fifty years will be spent in an elaboration of string theories, just as the last fifty were dominated by quantum field theories.

The story of superstring field theory re-started last autumn. The subject has been vigorously pursued during this year.What this conference may wish to register is the possible proof that quantum gravity - which naturally arises from excitations of closed strings - is possibly finite to all loop orders in this formalism. If this statement is borne out by future work, we shall have the first finite quantum theory of gravity: something which has eluded us all so far. For cosmologists, this will mean that we shall, at last, have a credible radiative extension of Einstein's equations - admittedly of use only when the Universe was very tiny in size, but of great conceptual significance nonetheless.

My own picture of the Universe is that it started life in two dimensions; one space, one time. Then there was a phase transition to 10 dimensions, followed by a second phase change to 4 dimensions and this is where we came in. I cannot forbear from repeating a remark due to Chris Isham at Imperial College. Chris said, when he started research, he went to quantum gravity; his hope was to discover the origin of the quantum of action within the context of general coordinate transformations - Planck as a part of Einstein. With quantised strings, one is succeeding, but in the opposite direction - Einstein's theory appears to be emerging from a small part of quantum theory!

Since this conference is devoting several sessions to these developments, I shall not take time to speak of superstring theories, except to remark that inflation plus strings may mean there may even be ramifications of string ideas for observational cosmology to-day. You will doubtless hear more of this in the context of the lens effect.

Let me conclude by saying - the science of astro-particle-physics is the fundamental science of to-day and we are fortunate that Marcel Grossmann meetings provide the right forum for practitioners of diverse aspects of this discipline to meet and share each other's insights.