The Expanding Worlds of General Relativity. Hubert Goenner, Jurgen Renn, Jim Ritter, Tilman Sauer (eds). Birkhäuser Verlag AG, P.O. Box 133, CH-4010 Basel, Switzerland. 1998. 528 pp. Price: SFr 128/DM 148.

General Relativity (GR) is undoubtedly one of the finest creations of the human intellect. It is thus not surprising that it has attracted an overwhelming consideration and attention apart from physicists and mathematicians, also from philosophers and historians of science. There has been considerable interest in historical and philosophical studies of gravitation and relativity. The main reason for such a universal appeal is not so much only due to the beauty and elegance of the theory, but also because it refers to the most fundamental and universal concepts of space and time. This is why it attracts much greater and wider discussion than its rival, the quantum theory. As a matter of fact, it is as basic as the earth being round, the fact that every sensible person knows or should know. Gravitation determines the geometry of the Universe we live in and hence what 'shape' the Universe has should be of interest to everyone.

The volumes in the Einstein Studies Series which form the proceedings of conferences, document the historical development and the present volume is the account of the fourth conference held in 1995 at the Max Planck Institute for the History of Science, Berlin. The main focus of discussion and debate at these conferences is to study and investigate how new concepts and breakthroughs were achieved in the context of the contemporary intellectual environment and their relevance and connection with the present research and understanding. These volumes will thus attract a specialist as well as a general reader interested in science and its evolution.

The volume is divided into four parts: 'Relativity in the making', 'Relativity at work', 'Relativity at large' and 'Relativity in debate'. Each part has 3–4 essays. Part I has four essays dealing with the early attempts of measuring gravitational absorption, Minkowski and his contribution to special relativity, Einstein's search for gravitational field equations and the role of rotation on the way to GR. The first essay alludes that formulation of a field theory for gravitation was on the agenda ever since the success of the Maxwell theory. The models and experiments were devised to investigate properties of the field like induction, wave propagation and absorption. Strange though it may sound, very respectable people were involved in these studies including Majorana, who essentially measured nothing but experimental errors, and Einstein, who gave a wrong explanation for the lunar fluctuations, the question was ultimately settled after a long debate by recognizing a proper measure of time.

We all know Minkowski's contribution in the geometric formulation to special relativity which has played very important role in subsequent development of GR and later-day field theories. He was a mathematician who was always uncertain of his physical ground. His formulation did not initially receive acceptance amongst physicists, notably two of his own students, Einstein, the creator of the theory and Laub. Planck and Wien appreciated the elegance and beauty of the 4-dimensional formulation. Sommerfield was amongst the first to see the real potential of the Minkowski's geometric space–time formulation. In his famous Cologne lecture, Minkowski indulged into a great bit of rhetoric to solicit support and there came the often quoted phrase, 'space by itself and time by itself are to sink fully into shadows and only a kind of union of the two should yet preserve autonomy'. And a good bit of support came from other Gottingen mathematicians who dominated the field in the early years. After Sommerfield's intervention the Gottingen physicists Walter Ritz, Max Born, Max Abraham and Max von Laue also fell in line. On completion of GR in 1916, Einstein did acknowledge Minkowski's formulation of special relativity.

The next two essays are on Einstein's tedious and spiraling path to GR field equations via the Machian ideas and rotation which concluded in 1915. It is wrought with comedy of errors, false starts, blunders as well as great insights and quantum jumps. There is a very interesting account of the journey from formulation of the principle of equivalence in 1907 through the stormy years of 1912–1914 and finally the year 1915. In the intermediate period, theories were either not covariant or gave ridiculous value of 18 for the Mercury perihelion shift. Einstein had the benefit of interaction and collaboration with two of his friends Marshall Grossman and Michael Besso, who were mathematically better accomplished than him. Interestingly, there is no reference to the Einstein–Hilbert controversy on the derivation of the gravitational field equation for non-empty space.

In part II, Peter Havas begins by recounting the good old Vienna days. It is a first-hand account by one who had seen the early surge of work on GR and its subsequent decline as the open and free environment got closed. It is the story of a town in relation to the development of a nascent field told with affection and insight. It is gratifying to see that work in GR has picked up again in Vienna in recent times with summer workshops at the Schrödinger Institute.

Then there is the essay on gravitational radiation and the controversy and debate on the quadrupole formula. GR is a non-linear theory which means some bit of ambiguity and good bit of mathematical complexity are inherent. Gravitational radiation must exist and it must propagate as a wave. How does one verify this? One way would be to derive a wave propagation equation from the Einstein equation. This always involves choice of a coordinate condition analogous to the Lorentz condition of the Maxwell theory. Here is a good bit of scope for ambiguity, which was the source of confusion. The other way is to show decrease in energy of a system which is being taken away by gravitational radiation. In 1916 Einstein began by predicting gravitational radiation, and claimed its non-existence in 1936 in a paper with Rosen. There is an interesting episode related to this paper. The paper was sent for publication to *Physical Review*. When the referee's report was sent back to Einstein he was infuriated since the editor had shown the work to someone else before publication! It was H. P. Robertson (FRW model), who pointed out the error which was duly acknowledged by Einstein.

The question is inherently very involved and difficult and it depends upon the slow and fast motion, and weak and strong field approximations. It is undoubtedly a very tedious job. Here again there are two groups, one of purists whose forte is rigour and the other of pragmatists whose forte is workability. In

Warsaw and Chapel Hill conferences, Feynman implored relativists for being too rigorous and asked them to be practical and to compute or else they would not be able to make any progress. In the sixties Bondi and his colleagues at the King's College, London did the pioneering work on gravitational radiation. The seventies and the eighties witnessed intense debate on the quadrupole formula controversy which withered away at the strength of the observation of the orbital period reduction of the Hulse–Taylor pulsar. Ultimately it was the Feynman's view that prevailed.

The next essay deals with the question of singularities. Initially scientists believed that singularities existed but without a proper definition. The Schwarzschild solution provided an excellent example for discussion in the context of $r = 2M$ and $r = 0$ singularities. The confusion persisted and no clear insight emerged until the seminal work of Amal Kumar Raychaudhuri of the Presidency College, Calcutta in 1955 and independently of Arthur Komar. The Russian school, initially affront, actually brought the issue in the focus and then the powerful theorems of Penrose, Hawking and Geroch emerged. Apart from the conclusive answer to the question of occurrence of singularities in GR, this work brought forth new geometrical techniques of global analysis which have proved very useful in theoretical physics in general. The theorems stated that occurrence of singularity is inevitable under the very general and almost self-evident assumptions of causality and positivity of energy. The question of what is a singularity still remains as open as ever. We are still far away from a precise and fully acceptable definition, though there exist some good workable definitions as termination of particle trajectory, blowing up of curvature and physical and kinematical parameters. What do the singularities signify – breakdown of theory or limit of space–time . . .? These are the pertinent questions that point to new directions.

Part III deals with applications to cosmology, the field that always occupies the center stage in any discussion of gravitation and relativity. The first essay discusses the Newtonian theory and difficulties in its application to the Universe as a whole. If the distribution of matter is homogeneous and the Universe is infinite in extent, then the questions like the well-known Olber's paradox, infinite mass and vanishing average density would arise. Various ways to overcome paradoxes included modification of the inverse square law, negative mass and non-Euclidean geometry, etc. No worthwhile insight was gained until Hubble's discovery of recession of galaxies from each other. With this fact and an appeal to relativity of acceleration, Milne and McCrea and others were able to develop the Newtonian cosmology on parallel lines as the relativistic FRW cosmology.

It is interesting to note that both Newton and Einstein stumbled while applying their theory to the Universe as a whole. Newton did not consider any problem in its application and hence did not address the question at all while Einstein as is well-known had the opportunity to commit the greatest blunder of his life!

There is an essay on Weyl's reflections on cosmology. Weyl was perhaps the first person to realize the question of causal connection in cosmology and hence postulated a cosmic time. There is a good discussion on the evolution of Weyl's principle through the twenties and its culmination with Robertson's adoption in the FRW model. Weyl's principle had a great influence on future developments in the field of cosmology. Both the big-bangers as well as the steady staters used Weyl's ideas at a varying level of strength to formulate their cosmology and world view. There are two complimentary ways of doing science and cosmology. One is to extrapolate from observations and experiments to form a principle and a theory while the second relies on the inner logic, harmony and aesthetic and philosophical imperatives to formulate a principle and a theory and then apply it to the observation. Of course the question attains greater significance when the observations and empirical base are limited. It is therefore not surprising that cosmologists were quite strongly divided into the two schools of thought, the empiricists included Dingle and others while the deductionists had many influential people like Milne, Eddington, Dirac and Bondi. Tolman was for the golden mid path. In the absence of hard observations, it is not surprising that the second group held sway.

Based on the observation as well as the aesthetic–philosophical principle that the Universe looks the same from anywhere and in any direction at all times, Bondi and Gold, and Hoyle took in 1948 a bold step to propose the idea of steady state cosmology. It was aesthetically very appealing and soothing but physically rather too bitter to gulp. For, to maintain an expanding Universe in the same state, it is necessary to create matter continually out of nothing violating the most sacred principle in physics, the conservation of energy. Despite this, the theory was taken very seriously perhaps with this doubt in one's mind that stranger may be the ways of the Universe at large.

One of the greatest contributions of the steady state theory was to pose challenges to astronomers who sharpened their tools and instruments to disprove it. It has thus contributed enormously in advancement of cosmology even if it turned out to be invalid. Its relation to GR was affront in the Bondi–Gold version, while not in the Hoyle–McCrea version where attempts were made to include it in the Einstein equation by bringing in creation of matter or matter with negative pressure. GR was soundly established in the mid sixties by lab experiments using microwaves verifying it as well as the observation of the cosmic microwave background radiation which is the key for prediction of the GR–FRW model. The latter proved a fatal blow to the steady state theory from which it never recovered, though in the nineties there was a courageous effort by Hoyle, Narlikar and Burbidge to resurrect it in the quasi steady state form. Precisely in the mid-sixties there was another revolutionary development in GR, the prediction of the black hole and its potential existence as an astrophysical object powering the most luminous objects ever discovered, the quasars. Thus GR was well established and the steady state theory had to work within its premise.

Part IV of the book deals with Larmour's objection to GR and the question of general covariance and modalities of coincidences in making observations. It is quite an involved debate and I would restrain from commenting on it except to say that for an interested reader there is an engaging discussion.

One of the important questions which is very fundamental for any theory and which has not been discussed in this volume is the initial value problem. It is rather surprising that after formulating

GR, Einstein did not seriously address this question. S. Chandrasekhar had also voiced the same opinion in a private conversation with the reviewer. It is remarkable that this volume too did not address this question.

On the strength of the powerful singularity theorems, it was generally believed including relativists that singularity is unavoidable in GR for physically reasonable behaviour of matter. This is wrong. In 1990, a young Spanish relativist, Jose Senovilla (*Phys. Rev. Lett.*, 1990, **64**, 2219) obtained a cosmological model without singularity and its matter content had perfectly accepted behaviour. This had shocked the entire scientific community including relativists. This was because no due heed was paid to one of the assumptions, which required the existence of a compact trapped surface. In a simple way, it means that it has been assumed *a priori* that the gravitational field would become strong enough to trap photons. Truly, it destroys generality of all the other assumptions which are almost self-evident and seriously hampers their applicability. Because how the field should behave should be left to the field equation, and postulating formation of trapped surface is no short of putting a singularity. It is however a different matter that the actual Universe might have been born in the Big-Bang singularity. It would have been appropriate to make this point in the essay on singularity. However, it would perhaps take some more time for historians of science to take its cognizance.

Today it is simple to understand the existence of zero rest mass particles which would not be at rest relative to any observer and hence must move with the same speed relative to all. The incorporation of this fact in mechanics leads to special relativity. Further making photons to interact with gravity would lead to the realization that gravity must curve space leading to GR. With this in view, it is always very fascinating to read the history of evolution of physical ideas, concepts and theories. The present volume precisely does this wonderfully.

N. K. DADHICH

Inter-University Centre for Astronomy and Astrophysics,
Post Bag No. 4,
Ganeshkhind,
Pune 411 007, India

Annual Review of Nuclear and Particle Science 1998. Vol. 48. Quigg, Luth and Paul (eds). Annual Reviews Inc., 4139 El Camino Way, Palo Alto, California 94303–0139, USA. Price: Individuals $ 75, Institutions $ 150. 566 pp.

The 11 review articles appearing in this issue provide upgradation of the material available in some of the frontier areas of research in nuclear physics (3 reviews), particle physics (6 reviews), nuclear astrophysics (1 review) and application of accelerators in nuclear technology (1 review). This is the only review dealing with pure physics, limited to nuclear and particle physics. It is a mind-boggling proposition to review technical articles in the four fields mentioned above. Nevertheless, an overall perspective is provided here.

In the area of nuclear physics, all the three reviews deal with heavy ion reactions: on nuclear structure through the Coulomb excitation of low lying states, the excitation of the multiphonon giant resonances in nuclei both at intermediate energies and on measuring barriers to fusion from low energy fusion reactions.

T. Glasmacher reviews Coulomb excitation at intermediate energies. Coulomb excitation is a well-established technique for probing the nuclear structure. The extension of this technique to nuclei far from stability to obtain their structure is the main focus of this paper. It involves detection of inelastically scattered particles at very forward angles and measurement of gamma rays from the Coulomb excitation process in coincidence, employing a large array of detectors. The Coulomb excitation cross-section is related to the electromagnetic matrix elements. Some of the highlights are B(E1) value for the first excited state of ^{11}Be, the only neutron halo nucleus having a bound excited state and the observation of weakening of $N = 20$ magicity for ^{32}Mg and $N = 28$ magicity for ^{46}Ar and ^{44}S. On the theoretical front the relativistic mean field and Monte Carlo shell model theories successfully reproduce some of these features.

T. Aumann, P. F. Bortignon and H. Emling deal with multiphonon giant resonances in nuclei. Giant resonances (GR) are highly collective excitations of the nuclei occurring throughout the periodic table and are of different types. In recent years two-phonon giant resonances (TPGR) have been measured from heavy ion reactions at intermediate energies and pion-induced double charge exchange reactions. The properties of multiphonon states provide an answer to the fundamental question on the strength of the phonon–phonon interaction and the anharmonicity. The mean field description – the random phase approximation (RPA) – gives a good account of GRs in general. High energy heavy ions are suitable for excitation of multiplication GRs as the required cross-sections are large, and the non-resonant backgrounds are relatively less using these probes. It is observed that the E_x and the width of TPGR are, respectively, about 2 and 1.5 times that of the single GR. Much more work needs to be done both theoretically and experimentally.

Dasgupta *et al.* deal with fusion barriers. Reactions of interacting nuclei at near Coulomb barrier energies are strongly influenced by the coupling between their nuclear structure and relative motion. Coupling of entrance channel to other channels leads to multiple fusion barriers, with some of them lying below and others above the original uncoupled barrier. The fusion cross-sections represented in the form of a barrier distribution enhance the sensitivity of the data to structure aspects of the fusing nuclei. The role of target deformation (quadrupole and hexadecapole) has been brought out from fusion studies involving ^{16}O + ^{154}Sm and ^{186}W systems; the coupling to target phonon states or projectile excitations have come out, respectively, from ^{16}O + ^{144}Sm and ^{40}Ca + ^{194}Pt studies; the importance of multiphonon excitations has resulted from data for Ni isotopes. The fusion barrier distribution shows increased sensitivity to the break up the channel in the case of weakly bound projectiles.

Particle physics has developed in the last four decades as the one involved in the description of the four fundamental processes, specifically dealing with the unification of the fundamental interactions – the gravitational, the electromagnetic, the weak and the strong interactions. The latter three are described by the quantum guage field theories with running coupling constants which describe interaction among fermions by the mediation of guage vector bosons. The strong interaction is well-described by the quantum