Natural Sciences

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The Astronomy, Cosmology and Particle Physics Connection

This talk is not a scientific lecture. I will be talking about science, which, being trained as a scientist, I am not accustomed to do. However, following the aim of this symposium, I will try to present to you some of the trends one can identify in the natural sciences. You will notice that these trends are mostly driven by the state of our knowledge and by the scientific questions, which have to be answered in order to allow scientific progress. They are not driven by the economic market. Also, very importantly, natural sciences being experimental sciences, they depend strongly on the development of technology.
Natural sciences include a large variety of scientific disciplines: astronomy, astrophysics, chemistry, cosmology, earth sciences, physics, sciences of the environment. Biology, also a science aiming at understanding nature, is often separated into the category of 'life sciences'. Today, I will concentrate on one domain, which contributed to several of these disciplines, some of which evolved later into a life of their own. I call this domain: The Rise and Fall and Rerise of Cosmic Rays.

The Rise

It all began in the late 19th Century with the slow and mysterious disappearance of electric charge observed in the electroscopes widely employed by investigators studying static electricity. After possible instrumental problems had been eliminated, most investigators resolved the question of what produced the observed effect as a terrestrial radiation. Among them, however, were a few exceptions, including the Austrian Victor Hess. By carrying a charged electroscope in balloons to high altitudes in the atmosphere, Hess proved that the cause of the leakage rate of electrical charge was not a terrestrial radiation, but radiation arriving from outside the atmosphere.
His dramatic discovery in 1911–1912 of a penetrating extraterrestrial radiation, later called cosmic rays, arose from his ***persistence in searching for the right answer*** to what appeared to be a minor instrumental problem of little importance to most of the investigators at that time.

We know now that the gases of our atmosphere are a target for the arriving cosmic ray nuclei, which span all the nuclei of the periodic table of elements from Hydrogen to Uranium. During their acceleration and propagation in the interstellar medium of the galaxy, these elements have been totally stripped of all their electrons so that they arrive in the solar system as bare nuclei. The geographic latitude of access to the atmosphere by the charged cosmic ray nuclei is determined by the external geomagnetic field, a property of our Earth. For example, only nuclei with energies larger than 12 GeV[23] per nucleon enter the geomagnetic equator, whereas all but the lowest energy nuclei have access over the polar region and produce a nucleonic cascade that can be detected on Earth.
The latitude effect was used both to prove that cosmic rays were mostly positively-charged particles and to show they had a broad energy distribution. Indeed, cosmic rays exist over the largest energy and intensity range of any known radiation in the universe. The energy spectrum covers more than twelve orders of magnitude, while changing in intensity by more than thirty orders of magnitude.
Although the galactic cosmic ray intensity is constant on time scales of millions of years, the intensity at Earth has been known since the 1930's to vary on time scales of hours, days or months. By the early 1950's it was proved that interplanetary dynamical processes of solar origin were the source of these intensity changes. Modulation in solar activity and the 11 year solar magnetic cycle alter the dynamical conditions in the heliosphere (i.e. in the solar environment, which totally encloses the solar system), and, thereby, they modify the trajectories of the incoming galactic cosmic rays.
The isotopic composition of the elements in the cosmic radiation is the key to our understanding of their nucleosynthetic origins, to all aspects of their acceleration, to the wide range of cosmic ray energies, and to the chronology of cosmic ray propagation in the galactic disc and magnetic halo. In contrast with elemental abundance the relative isotopic abundance of an element does not possess any known bias during acceleration and propagation. Radioactive decay isotopes provide information on the time between nucleosynthesis and their initial acceleration, or time of propagation in the galactic magnetic field, i.e. cosmic ray age. For example, one obtains an age of 12 to 18 million years for the galactic containment.
High energy primary electrons were first directly identified in the 1960's. At the level of only a few percent of the number of protons, they are both positively and negatively charged.
Cosmic ray research has contributed to many disciplines in astrophysics and high energy particle physics. These include discoveries in such fields as gamma-ray and radio astro-

23 = 12 GIGA eV, i.e. 10 million times the energy of electrons in a television set

physics, nucleosynthesis theory and particle physics. It served to discover new elementary particles, like the positron or the cascade minus hyperon Ξ^-, to develop radioactive particle dating (by Carbon-14 in the atmosphere, for example) and to date geological formations. It is also recognized that cosmic ray research required the development of many innovative particle detectors, like cloud chambers, neutron detectors and so on.

The Fall

However, in elementary particle physics, over the years, ***the study of cosmic rays has been almost completely replaced by accelerator experiments***, when beams of well identified, momentum analyzed particles became available. This physics research requires large facilities, affordable only at the level of a very large country or a continent.
CERN, for example, was founded in 1954 by 12 European countries and it constructed its laboratory in Geneva, building a series of high energy particle accelerators. Notice, however, that the CERN Convention also mentions the study of cosmic rays in its mission. CERN now belongs to 20 European states and several non-member states have obtained the status of observer.
The development of particle accelerators in the world is illustrated in the so-called Livingston plot. In order to reach higher and higher energies, new types of accelerators have been invented, followed over the years by periods of improvement. The accelerators are physically located mainly in advanced industrial countries.
In developing countries, where access to large particle accelerators is too expensive, ***a large interest for cosmic ray research has been maintained***, especially where high altitude cosmic ray detectors can be installed. This can be demonstrated by the attendance to the International Cosmic Ray Conference held every two years since 1947 by about 500 delegates from 35 countries.
The decline in the interest for cosmic ray research is illustrated in Switzerland in 1992. It was a time when the SNF was still obliged to define to Swiss authorities its priorities and posteriorities, a perilous exercise; well, it declared cosmic ray study as a posteriority.
What will be the priorities of particle physics in the 21st century? Today particle physics is fully described by its Standard Model, describing very precisely all observed particles and their interactions. However, there are unresolved problems. What is the origin of particle masses, are they due to a Higgs boson mechanism, and, if so, why are they so small, perhaps because of supersymmetry? Is there a simple group framework containing the strong, weak and electromagnetic gauge interactions, and does it predict new observable phenomena such as proton decay and neutrino masses? Why are there so many types

of quarks and leptons, and how can one understand their weak mixing and CP (charge conjugation times parity) violation, is it perhaps because they are composite or have extra symmetries?
The development of this discipline presently follows both from ***scientific proposals aiming at solving these fundamental questions*** and from ***the development of accelerator technology*** (remember that the 1984 Nobel prize for the discovery of the intermediate bosons W and Z in proton anti-proton collisions was given both to Carlo Rubbia who masterminded the experimental program and to Simon van der Meer who devised the sophisticated antiproton stochastic cooling feedback system).
Scientists play an important role in defining future strategies for new facilities at CERN, as well as at other international scientific organizations such as ESA or ESO. As such projects are expensive in equipment and personnel, large international collaborations, consortia have to be formed.
In the case of particle physics, scientists are well organized for defining priorities among themselves with organizations such as the European Committee for Future Accelerators or the International Committee for Future Accelerators. However, the effectiveness of the lobbying power of scientists towards governments has not been demonstrated.
A very recent example is the observation of the Higgs boson at CERN. The pressure of the scientific community did not succeed in extending the operation of the LEP accelerator for further experimental confirmation.
In construction are major facilities: the Large Hadron Collider at CERN, b meson factories elsewhere. Various laboratories are proposing electron-positron linear colliders with center-of-mass energies between 500 GeV and 5000 GeV.
The study of neutrinos deserves to be mentioned here. The interest for neutrino detection originated in the mid-sixties: in particular the observation of neutrinos emanating from the solar core and registered on Earth by large underground detectors. Recently, it was recognized by the scientific community that these experiments are addressing not a vague astrophysical puzzle, but a fundamental physics problem, a step beyond the Standard Model of electroweak interactions. Very large facilities are being commissioned such as Gran Sasso in Italy and SuperKamiokande in Japan, while plans are made for very large under-water detectors.
The production of neutrinos from the decay of muons circulating in a storage ring (neutrino factory) has of late attracted considerable attention. This very new situation has arisen with the recent confirmation of neutrino oscillations. High-energy muons, stored in a decay ring with long straight sections pointing towards distant detectors, would provide a unique beam of high-energy electron neutrinos. A substantial R and D effort will be required.

As the competition for big science is getting stronger and as awareness for the needs of society is increasing, particle physicists are getting more involved with practical applications and public communication. A new trend is thus appearing within the large particle physics labs. One can list four new areas:
- Medical applications (positron emission tomography, hydrotherapy, ...)
- Technology transfers to the private sector
- Ethical questions
- General public and youth programs to explain the methods and the results of scientific research.

The Rerise

A renewed interest for cosmic rays has appeared as facilities have been made available today by space-transportation and telecommunication: experiments can be installed on spacecraft to detect charged particles and photons in space. Motivation to put detectors in space comes from cosmology, astrophysics, particle physics, as well as solar and earth environment research. This trend is thus driven by technology and scientific considerations. Commercial applications are not foreseen.
The combined development of particle physics and astrophysics has given birth to a new field called astro-particle physics. It is now present in traditional high energy physics and detector conferences. It also includes X-ray and gamma-ray space observation. Gamma-ray emission can find its origin in the active nuclei of other galaxies than our own.
Remember now the four pillars on which rests the standard model of cosmology: the isotropic background radiation, the homogeneity of the universe on a large scale, the recession of the galaxies (i.e. the red shift of the light emitted by luminous objects) and the relative primordial abundance of the light elements in the universe. This model is remarkable as it allows to contain these experimental facts.
It is becoming clearer that the primordial universe gives access to phenomena, which happen at energies well beyond the most powerful accelerators on earth. Cosmological observations allow an alternative way to particle physics beyond the standard model. The observation of the anisotropies of the relic radiation has started a new era where cosmological experiments have reached a precision sufficient to test physical models in domains, which are not accessible in earth labs. Cosmological experiments can in this sense complement particle physics experiments performed on Earth.

Several important questions are still without an answer:
- The composition and amount of dark matter (thought to form about 90% of the mass of the Universe)
- The formation of the large scale structures
- The origin of the matter-anti-matter asymmetry
- The origin of the homogeneity.

In order to improve the standard model of cosmology, scenarios of inflation and baryogenesis have been imagined. They allow to understand a little better these experimental facts, at the expense of the original simplicity: for example, the apparent absence of local or global anti-matter can be explained by baryogenesis scenarios, which however cannot predict the baryonic fraction in the Universe.
What is needed here is a direct search for antimatter in space. Fortunately such an experiment is being prepared. It is the Alpha Magnetic Spectrometer, a large acceptance, very precise cosmic ray detector to be flown in space on Earth orbit. It is interesting to recall that the project started thanks to the announced opportunity of the International Space Station, the strong support of the NASA administrator Mr. D. Goldin, and the energy and vision of Nobel laureate Samuel Ting. I joined the project very early on with a team from the University of Geneva, followed a year later by a group from ETH Zurich.
Finally, let me mention a new proposal concerning cosmic rays at the intersection of astrophysics, particle physics, earth sciences, chemistry. A striking correlation has been observed between global cloud cover and the flux of incident cosmic rays. The effect of natural variations in the cosmic ray flux is large, and could cause changes in global temperatures on Earth that are comparable to the warming attributed to greenhouse gases from the burning of fossil fuels since the Industrial Revolution. Experiments are proposed to measure cloud formation under controlled conditions in a particle beam simulating cosmic rays. Are we witnessing the birth of a new cross-disciplinary research originating with cosmic rays?
In conclusion, numerous projects of cosmological experiments, space experiments, and the future experiments at the Large Hadron Collider will hopefully resolve in a complementary way a still unsatisfying present scientific situation. I hope I have shown to you that these projects are mostly driven by the curiosity of dedicated scientists in basic research.

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Cultural Disconnections

In my short comment I'll concentrate on three main points, which I make as an outsider, lacking any expert knowledge but trying to be a "well-informed citizen". I follow here the distinction made by Alfred Schütz on three ideal types of knowledge or knowing: the expert, the "man on the street" and the "well-informed citizen".[24] To take up this last position vis-à-vis the natural sciences is not very easy, because substantial information is scarce and often more veiled than communicated by the expert's language.[25]
First: If there is a mega-trend in the natural sciences it is probably not within physics. On the contrary, the methods of physics have become so commonplace everywhere other fields may raise to prominence. Secondly: This might entice physicists to adopt almost propagandistic ways of 'selling' their often quite expensive disciplinary undertakings. Thirdly: It might be wiser to try to form a well-informed public, to insist on the fact that the applicability of any decent research is not predictable and that science is part of our culture.
Ad 1: For any outsider it seems quite evident that the present megatrend in the sciences lies in molecular biology and genetics, not in physics – although maybe in new (re)combinations of disciplines. This goes along with new ideals of theory-building and often rather fantastic imaginations of applicability. Physics has been for a very long time the absolute ideal of scientific thinking, copied more or less successfully by almost all the other academic disciplines, including the social sciences. (This is one of the origins of the success-story of neoclassical theory in economics). Nowadays the scientific and public interest seems to be shifting from matter (and antimatter), from the physical micro- and macro world to the ground plan of life. The Human Genome Project with its many proliferating non-academic branches is not only absorbing public money and public interest, but also adds to the attraction of the Life Sciences for students within the universities.

24 Cf. Alfred Schütz, "The Well-Informed Citizen. An Essay on the Social Distribution of Knowledge", in: *Collected Papers II*, The Hague 1964, 120-134.
25 Media information is also rare. So I tried to inform myselve by reading popular books written by scientists. Helpful were Brian Greene, *The Elegant Universe*, New York 1999 (dt. 2000); Frank Grotelüschen, *Der Klang der Superstrings. Einführung in die Natur der Elementarteilchen*, München 1999. I thank Daniel Wyler for his critical, but useful comments on an earlier draft of this mini-paper.

Expressed in the metaphors of decoding and deciphering the hidden script of life, research in genetics gives the impression of breathtaking advances and quite consciously holds out hopes to their immediate applicability. Here is not the place to discuss these exaggerated hopes nor the dangers inherent in the structure of a genetic determinism. Suffice it to say, that the genetic adventure with its appearance of liveliness and versatility is a big challenge to the 'Elegant Universe' (Brian Greene) of particle physics and its cold quest for the ultimate theory. I hold it to be dangerous for anybody (whether as participant in everyday life or as well-informed citizen or as expert in what domain so ever) to ignore and therefore not to try to understand the development and to grasp the inner logic of this specific megatrend at the beginning of the 21st Century.
Ad 2: I fear that Prof. Bourquin's arguments have not convinced me – in my role as "well-informed citizen" – that what he was talking about could turn out to be a megatrend in the natural sciences. I did not have the feeling that he was trying to inform me (and you) about a possible megatrend, but that he was using the opportunity for a semi-political talk about the necessity of the Large Hadron Collider at CERN and the tremendous value of AMS (Alpha Magnetic Spectrometer) on the International Space Station.
There are four different kinds of arguments in his paper, concerning a) the theoretical (or aesthetic) incompleteness of the standard model, b) the special place of cosmic ray physics for new insights, c) the relation between science and politics or the public and in the end d) hidden promises of usefulness.
Ad a) and b) It has been a fascinating intellectual adventure for me to take a walk on the mild side of particles and hidden dimensions and perceiving the vibrations of superstrings. One lesson I learnt: There still is a potential for changes and the emergence of new ideas. SUSY might be a vanishing dream and even the famous Higgs might show up in an unexpected way. Asked about the central paths for possible new discoveries, I would expect different answers from someone at Fermilab or at a Beauty factory (such as BaBar and Belle). And I suspect that I could hardly find a serious physicist (still willing to find a job) who would tell me that the LHC might not be able – I quote – "to resolve in a complementary way a frozen present scientific situation".
This leads me to the arguments c) and d) and Prof. Bourquin's assumption that as competition for big science is growing stronger, "particle physicists are getting more involved with practical applications and public communication". I did not get the impression that Prof. Bourquin really communicated with me. The theoretical expositions were put forward in a way to impress and intimidate me and/as the public. Not even the 'woman on the street' would believe in this kind of scientific functioning. And the implicit promises (inspired by words like "changes in global temperatures" and "the burning of fossil fuels since the Industrial Revolution") are misleading. This brings me to my third and last point.

Ad 3: Besides the megatrend of the Life-Sciences, much less concentrated and centralized than research in physics and tightly connected with business, there is another megatrend. I refer to the take-over of economics and the urge to put everything and everybody under the logic of costs and benefits and profits – with the corollaries of efficiency, utilization, practical application etc.
In this situation it seems vital that scientists insist on the cultural (or even aesthetic) dimension of their thinking and doing and on the fact that we do not know all about usefulness or uselessness beforehand. And that we even know less about possible by-products (like the World Wide Web).
Taking up an old idea of the physicist and chemist Michael Polanyi: All science is about understanding (not only the "Geisteswissenschaften", but also the natural sciences).[26] We want to understand the universe, the Top-Quark, the genes and the structure of the expert's knowledge. Like operas, physics is part of our cultural heritage and thus of our collective identity.
Maybe the political solution would be to put the sciences under the responsibility of a ministry of culture.[27] In any case we need a better informed public (not ghostly assemblies of public acclamation) – a public able to judge and thus legitimize decisions on conditions for scientific research. Efforts must be made on both sides: People willing to become well-informed citizens and scientists willing to inform them. This might be the only way out of the present state of mutual misunderstandings and cultural disconnections.

26 Cf. Michael Polanyi, *Personal Knowledge*, London 1958.
27 Cf. Hans Graßmann, *Das Top Quark, Picasso und Mercedes-Benz oder Was ist Physik?* Reinbek b. Hamburg 1997.

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Petit, j'étais passionné de violon. J'ai bien connu Alfred Costat, un grand pianiste français. Un jour, il vient chez moi et me dit, Pascal, joue-moi un morceau de piano…
Et bien, j'ai eu la même panique ce jour-là qu'aujourd'hui où je dois faire quelques commentaires sur le passionnant exposé de Monsieur Bourquin: je me sens complètement incompétent.
La science, que ce soit la physique moderne, la biologie ou la médecine, s'est bâtie autour d'une conception atomiste de la Grèce antique, selon laquelle la matière est faite d'atomes.
Ainsi le monde est fait du mélange de briques infiniment petites, dont la composition est à la base de la variété qui nous entoure.
L'étude de l'univers a montré un emboîtement des structures, qui deviennent de plus en plus complexes dans l'infiniment grand et l'infiniment petit. Cependant, selon Mayer Baliant chaque niveau de complexité est entièrement conditionné par le niveau inférieur, ne nécessitant aucun postulat nouveau, et ses lois ne sont en principe que des conséquences des lois du niveau inférieur. Cette hypothèse réductioniste ne doit pas exclure une autonomie des lois de systèmes complexes comme celles de la biologie, qui vont bien au-delà des lois de la physique élémentaire, tout en les respectant.
Ainsi, la physique des particules est à la base des sciences de la vie et de la médecine, dont elle a fixé des lois élémentaires sur lesquelles les lois de fonctionnement de la matière vivante se sont greffées.
A partir de là, que peut nous apporter encore l'astronomie, la cosmologie et la physique des particules?
Je dirais en premier lieu le rêve et la réflexion sur notre destin. Pour moi, les physiciens sont les philosophes et les poètes de la science qui nous posent des questions fascinantes.
A partir du big bang, l'univers va-t-il s'expandre à l'infini ou finalement imploser? Tout cela dépendra de la densité de l'univers et des trous noirs, qui selon les lois de Newton pourraient arrêter l'expansion de l'univers par gravitation.
Que sont les fameux trous noirs, comme celui situé près de la Constellation Sagittaire de notre galaxie, qui pèse probablement 1 million et demi de fois le soleil, et dont la présence n'est soupçonnée que par la danse spéciale des étoiles dans la région?
A une époque où l'esprit humain est pollué soit par des faits divers stupides, soit par des batailles de territoires et de pouvoir, la cosmologie pourrait contribuer à remettre l'échelle

des valeurs à sa juste place. Avec la poésie et l'art, cette science devrait être diffusée plus efficacement dans la population, pour nourrir la pensée de concepts enrichissants. Cette discipline, comme beaucoup d'autres, souffre du cloisonnement des connaissances et d'isolement. Avec la complexité croissante de la science, un des défis du monde actuel est de garder une perméabilité et une fertilisation réciproque entre les différents domaines scientifiques.
La physique des particules et la cosmologie auront certainement bien d'autres retombées sur les sciences de la vie. La plupart des appareils médicaux utilisent d'une façon ou d'une autre les connaissances dérivées de la physique, que ce soit les méthodes diagnostic radiologique ou de traitement par isotopes. Et comme toujours dans la science, les retombées sont souvent imprédictibles et pourraient concerner des domaines variés comme la recherche de nouveaux moyens énergétiques, l'environnement, etc…
Peu importe les retombées, personnellement, je suis prêt à donner la parole aux poètes de science que sont les physiciens et me laisser rêver.

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Prof. Bourquin hat es in faszinierender Weise verstanden, die wissenschaftliche Herausforderung im Zusammenhang mit der kosmischen Strahlung und Elementarteilchen-Physik darzustellen. Ohne Zweifel werden diese Forschungsfragen und vor allem deren Beantwortung wegweisende Erkenntnisse liefern. Sie könnten durchaus einen Megatrend darstellen, der zu einem diskontinuierlichen Entwicklungsschritt, sogar zu einem Paradigmenwechsel führen kann.
Aus der Sicht der technischen Wissenschaften taucht neben der wissenschaftlichen Neugierde und der Leidenschaft, Ursachen und Zusammenhänge zu ergründen, rasch die für Forscherohren profane, ja fast ketzerische Folgefrage auf: «Wie können neue wissenschaftliche Erkenntnisse in Produkte und Dienstleistungen umgesetzt werden?»
Die Zeiträume, welche zwischen wissenschaftlicher Erkenntnis und deren Anwendung in sichtbaren Veränderungen und neuen Produkten vergehen, sind meist sehr lang. So dauerte es mehrere Jahrhunderte, bis die wissenschaftlichen Erkenntnisse von Galilei und Keppler, aber auch von Newton im Rahmen des neuen Energie- und Industriezeitalters ab dem 19. Jahrhundert in Erscheinung traten. Es dauerte wiederum rund das ganze 20. Jahrhundert, bis Erkenntnisse aus Mathematik, aus Quanten- und Festkörperphysik zu dem im Gang befindlichen Paradigmenwechsel der Menschheit, nämlich zum Übergang von der Industriegesellschaft zur Informationsgesellschaft führten. Dieser Trend und die damit verbundenen Möglichkeiten mit dem Rohstoff Wissen ganz anders als bisher umzugehen, ermöglichte die sich heute abzeichnenden Megatrends in den technischen Wissenschaften. Neben den mit Datenbanken und Informatik verbundenen Aktivitäten wie Netzwerke, Wissensmanagement, intelligenten Komponenten, E-commerce etc. dürften im 21. Jahrhundert die Erkenntnisse aus Biologie und aus dem weiten Feld der Physik zu gewaltigen Umwälzungen und neuen Trends z.B. in Form von Nanotechnologie führen.
In welchem Zeitpunkt und in welcher Form die Erkenntnisse und Konsequenzen aus der Beobachtung der kosmischen Strahlung und der damit zusammenhängenden Phänomene der Teilchenphysik eine neue Umwälzung für uns bedeuten werden, ist noch kaum abschätzbar. Aufgrund der Transfergeschwindigkeiten der vergangenen Jahrhunderte ist es sehr wohl möglich, dass solche Erkenntnisse noch in der zweiten Hälfte des 21. Jahrhunderts zu neuen Produkten, Dienstleistungen und technischen Möglichkeiten führen könnten. Für die technischen Wissenschaften bedeutet dies eine hohe Herausforderung im Verstehen und Umsetzen. Aber auch eine spannende Zeit mit hoher Ungewissheit bezüglich Ziel und Weg.
Ob wir wiederum das Privileg haben werden, eine Person wie Leonardo da Vinci unter uns zu haben, bleibt offen. Er war Phänomen und Genie, indem er weitgehend intuitiv Erkenntnisse der Wissenschaft in einem Zeitpunkt in Produkte «umdachte», wo weder die Erkenntnis noch die Akzeptanz noch die Infrastruktur noch das notwendige Können vorhanden waren. Ich bin überzeugt, dass technische Wissenschaftler in grosser Zahl die Forschungsergebnisse im Zusammenhang mit der kosmischen Strahlung verfolgen werden und daraus auch Schlüsse ziehen, wie diese in verschiedensten Gebieten der menschlichen Bedürfnisse zur Anwendung kommen können.