suggest a simple conclusion: an international scientific institution will not be justified as such unless its related benefits to the community are vastly superior to those achievable by the national laboratories.

To answer many compelling questions of physics, Europe has an evolutionary strategy of providing accelerators able to meet the demands of research. The main impetus at the moment is from the Large Electron-Positron storage ring (LEP). By the end of 1991, each of the four LEP detectors had observed the decays of about half a million Z^0 particles and measured many properties of the Z^0 with extreme accuracy. For example, its mass has now been measured with a precision of 2 parts in 10,000 and its lifetime to an accuracy of 5 parts in 1,000. Perhaps the most important result, so far, is the discovery that for some as yet unknown reason there are only three kinds of neutrinos in the universe, implying that there are just three types of matter particles. Our next step in exploiting LEP is to increase the machine's energy to around 90 GeV per beam by the beginning of 1994. LEP II will be able to find new particles weighing less than about 90 GeV and extend precision measurements, such as those on the *W* particle.

These remarkably accurate data have clarified the way forward for particle physics and highlighted the possibility of exciting discoveries, such as the Higgs particle and supersymmetry. The next stage in the strategy for European particle physics is the new accelerator project, the LHC, which has the potential to make some of the most important scientific breakthroughs of our era. The LHC is a technologically challenging superconducting particle accelerator that will bring 7.7-TeV proton beams into head-on collision at higher energies than ever achieved before. It will be installed above the LEP collider in the same 27-kilometer tunnel, designed to accommodate the two rings.

The preparatory work for the LHC is going ahead and a milestone was passed in December 1991 with the unanimous agreement of the CERN Council that the machine is right for the future of particle physics and of CERN. The excitement generated by the LHC was demonstrated at a physics meeting in Evian at the beginning of March 1992, when 650 scientists from 29 countries met to discuss various experimental scenarios. There is great interest not only in colliding protons but also heavy nuclei, to generate "beauty" particles and neutrino beams. At a later date, proton beams from LHC can be collided with electron beams from LEP, opening up a whole new range of research. The LHC will be the most versatile accelerator ever available to particle physicists. The research potential of the machine is enormous and the most exciting prospect of all is the possibility that some of the discoveries that will be made will come as a complete surprise.

As well as CERN, there are other remarkable laboratories in Europe making major contributions with highly internationalized first class work. At the DESY Laboratory in Hamburg, the first collisions between electrons and protons took place in October 1991 in the HERA accelerator. This very exciting machine, with the most advanced superconducting proton ring in the world at present, will allow physicists to examine the inner structure of the proton with unprecedented accuracy.

A clear trend in particle physics research is the evolution away from separate experiments to general facilities where international cooperation has become absolutely essential. The desire to understand is universal, making science intrinsically international. The great discoveries made by scientists throughout history are the common property of all humanity and scientists have always sought collaboration beyond their own frontiers.

This thirst for collaboration has been highlighted by the political changes in Europe, and CERN has opened its doors to the East. Poland and the Czech and Slovak Federal Republic have become member states and final negotiations are under way for the accession of Hungary. Cooperation agreements have been signed with Bulgaria, Croatia, Romania, Serbia, and Slovenia. CERN's international standing has been reinforced by the observer status granted to Israel and the Russian Federation and by the cooperation agreements signed with Argentina, Australia, Brazil, Chile, China, India, Israel, and the Russian Federation. I see this as an important step toward profiting from the immense creativity generated by international scientific collaboration.

The strategy we adopted in Europe, to pool both financial and intellectual resources, has been enormously successful. We will continue to follow this strategy in the years to come. With our unrivaled range of existing facilities and our proposed new equipment, we can look forward to maintaining our position at the forefront of research well into the next century.

European Astronomy

Martin Rees

European cooperation in astronomy is so well developed that even the insular British will soon depend on international partnerships for their premier observing facilities. This trend toward collaborative projects is especially advanced in optical-band astronomy. This has come about because modern large telescopes are costly, and also because the best sites are remote from the European mainland.

The major optical partnership is the European Southern Observatory (ESO), with its suite of telescopes at La Silla in Chile. ESO's most recent success has been the New Technology Telescope (NTT). This instrument has a thin, somewhat flexible, 3.5-m mirror whose figure can be adjusted by active optics. This capability, combined with a unique building design that minimizes atmospheric turbulence, allows the NTT to obtain sharp images that take full advantage of the qualities of the site. The techniques will be incorporated in the Very Large Telescope (VLT), ESO's project for a telescope array comprising four separate, but linked, 8-m telescopes. This is the most ambitious project in the world in optical astronomy. The challenge is greater because of the decision to open up a completely new site in Cerro Paranal in northern Chile, where atmospheric conditions are even better than at La Silla.

Europe's prime Northern Hemisphere site is the Observatorio del Roque de los Muchachos at 2500-m altitude on La Palma in the Canary Islands. This was formally established in the 1970s as an international observatory. The host institution is the Instituto de Astrofisica de Canarias (IAC) on Tenerife which has, under the sustained leadership of Francisco Sanchez, become a major research center in its own right. The largest telescope at La Palma is the William Herschel 4-m, primarily a U.K. facility, but with 20% Dutch participation. There are also smaller telescopes, owned by the United Kingdom and by Scandinavian countries (most recently, the Nordic Optical Telescope). The Italians recently decided to place on La Palma their planned 3.5-m Galileo telescope, a clone of ESO's NTT.

La Palma, already Europe's premier Northern Hemisphere observatory, has obvious potential for further development, so that it becomes a counterpart for what ESO

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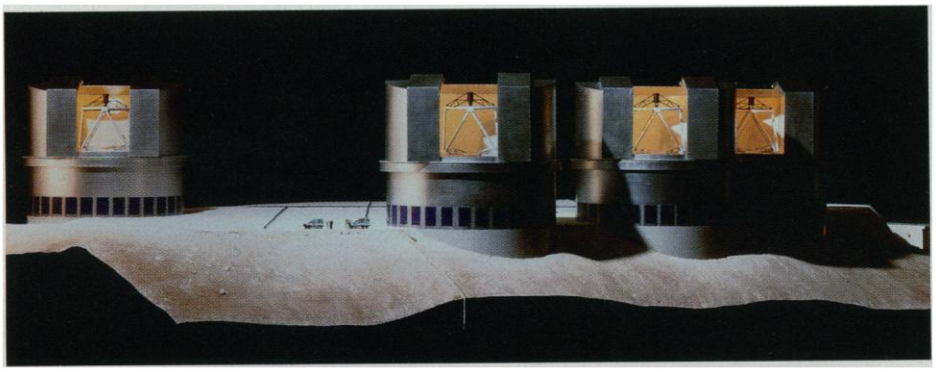
offers European astronomers in the south. This prospect has recently dimmed—though, one hopes, not foreclosed permanently—following the decision of the Science and Engineering Research Council (the United Kingdom's main funding agency for astronomy) to opt for a minority stake in the United States–led Gemini project rather than collaborating with Spain (and perhaps others) to construct an 8-m-class telescope on La Palma.

Europe's resurgence in optical astronomy dates from the 1970s, when, for the first time, it became feasible to utilize sites away from the European mainland—in the earlier part of the century the U.S. West Coast had unrivaled advantages. Now that their skill in innovative instrumentation is complemented by their access to large telescopes on good sites, European astronomers are making leading contributions to frontier areas of extragalactic research such as high red-shift quasars, gravitational lenses, and large-scale structure.

The climate was never an impediment to radio observations. Europe took an early post-war lead in radio astronomy and has maintained diverse strength in these techniques. There have been no overarching collaborations, as there are in optical astronomy and space research. Instead, the trend has been toward complementary projects in different countries. Among recent developments have been the Franco-German IRAM project and the James Clerk Maxwell submillimeter dish in Hawaii. The latter was primarily a U.K. project, though there is now Dutch and Canadian involvement. Manchester's Merlin multi-link interferometer was recently extended by the construction of a 25-m dish in Cambridge; its 100- to 200-km baselines offer angular resolution similar to the Very Large Array, but at lower frequency. These U.K. facilities can also be linked into the expanding European very-long-baseline interferometric network.

It is somewhat invidious to highlight the contributions of specific European nations, most of which have long academic traditions and distinctive areas of excellence. But I suspect that few would dissent from the view that one small country, The Netherlands, has made a disproportionate contribution to 20th-century astronomy. For most of this time, the outstanding figure has been Jan Oort. His classic researches on the rotation of the Galaxy date from the 1920s; he led the Dutch efforts in radio astronomy, was in the forefront of many European collaborations, and still remains active in Leiden University.

In ground-based astronomy—radio and optical—the European effort is fully competitive with that in North America, just as it is in most other sciences, even "big sciences" such as particle physics. But the one exception, still, is space science. Europe's space program, though excellent and successful within several areas, cannot in quantitative terms match NASA's. It was never spurred, as was that of the United States, by the superpower confrontation.



Scale model of the Very Large Telescope. Four 8-m telescopes will be linked together at a new site in Cerro Paranal in northern Chile. [European Southern Observatory photo]

Europe's main coordinated effort is through the European Space Agency (ESA). Pure science is only a small part of ESA's charter. But contributions to the science program are mandatory—unlike the major application programs in which nations participate on an "à la carte" basis. ESA's program has had a range of scientific successes. In the present decade, it is built around the recommendations of Horizon 2000—a program of four "cornerstone" missions, supplemented by smaller ones with a shorter planning lead time. There are concerns that the timetable is slipping because of the budgetary constraints. For instance, the x-ray astronomy cornerstone, XMM, will not now fly until the next millennium.

Some years ago Freeman Dyson, in an article entitled "Quick Is Beautiful" (*1*), expressed concern about NASA's mega-projects, and, by contrast, extolled ESA's Hipparcos astrometric project as an example of what should be done. It seems "quick" (almost 10 years' gestation) and "cheap" (around $300 million) only in the perspective of more grandiose space projects. But Hipparcos is achieving its goal of measuring up to 10^5 stellar positions over the entire sky, despite a fault in the booster which prevented it from reaching the right orbit. Dyson would perhaps be less happy with ESA's cornerstone projects, but at least ESA has the advantage of concentrating its resources on unmanned space flight.

One of ESA's highlights was the Giotto probe of Halley's comet. This same spacecraft will pass close to another comet (P/Grigg-Sjellerup) on 10 July 1992. The camera was unfortunately damaged during the Halley encounter in 1985, but other instruments should gather useful data on this very different cometary environment. ESA's early program downplayed planetary science, but this is now being remedied. A major solar system project is Ulysses. Early this year, the Ulysses spacecraft passed Jupiter and was gravitationally deflected onto an "out-of-ecliptic" trajectory that will take it over the solar pole in 2 years' time.

Germany, France, Italy, and the United Kingdom have national space projects which are not part of the ESA program. In many cases these are international partnerships. The IRAS satellite, a transatlantic partnership between NASA and Holland and the United Kingdom, was an outstanding success and produced a vast database that is still being exploited. The United Kingdom has had a successful program in x-ray astronomy. At the moment, equal success is being achieved by ROSAT, a German-led project in x-ray astronomy.

The European space effort—through ESA and national programs—has achieved a higher profile and greater competitiveness in the last decade, especially since the slowdown in the launch rate of U.S. scientific satellites.

It has naturally been within Western Europe that the strongest international collaborations have been forged. But for many years there were links, initiated by the French in particular, with the Soviet space program. In the Gorbachev era, collaborations encouraged by Roald Sagdeev (then the Director of the Space Research Institute) led to more substantial involvement in space hardware projects—for instance, the Spectrum X mission in x-ray astronomy. Other Soviet-led projects—for instance, the Radastron space interferometer and the proposed T-170 space telescope, with a 1.7-m mirror—have attracted substantial interest in Western Europe, and it is a matter of great concern to ensure that these do not founder.

The Soviets achieved great success in space research and also in theoretical astrophysics. But there are other distinguished centers elsewhere in Eastern Europe—Warsaw's Copernicus Center and the cosmology group at Tartu, Estonia, to name but two—whose viability is precarious in the present situation.

This is therefore an opportune moment for the foundation of the European Astronomical Society—explicitly (like the European Physical Society in physics) embracing the former "Eastern" countries—under the presidency of Lodewijk Woltjer, former Director-General of ESO (and, incidentally, one of Oort's many former students). Scientific societies do not have substantial resources at their direct disposal. But pan-European societies can play a role in ensuring that funds from the EEC and other bodies get channeled in the most effective way.

The style of astronomy has evolved toward multi-wavelength studies. In Europe this has led to international collaboration, not only at the level of big projects where it is forced by economic realism, but at the level of academic groups and individual investigations. There is a growing trend for students graduating with Ph.D.'s in one European country to move to another for their postdoctoral work. In the past, the United States was the most likely meeting place for such people. The integration of Europe has its controversial aspects, but in science the potential of greater Europe is already apparent. Astronomers are well placed to play an effective part in catalyzing a real European community.

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Genes to Greens: Embryonic Pattern Formation in Plants

Gerd Jürgens

Genetic analyses, in combination with molecular studies, have led to remarkable insights into the mechanisms that generate body organization in the embryo of higher animals (*1*). Plant developmental biology is just on the verge of taking the same direction, as indicated by recent advances in the understanding of flower development (*2*). In two widely divergent plant species, the common laboratory weed *Arabidopsis* and the snapdragon *Antirrhinum*, a small number of genes coding for transcription factors have been found to be crucial for the formation of floral structures. Although the flowers look very different in the two species, their development follows common principles: similar interactions of homologous genes. Thus, plant developmental biology is undergoing the same transformation that has revolutionized animal developmental biology in the past 10 years. Other aspects of plant development are also now being subjected to genetic analysis (*3*) and these studies are beginning to elucidate the mechanisms underlying the formation of the body organization in the embryo.

The idea that the body organization of plants is laid down in the embryo, like that of animals, runs counter to traditional views, which have stressed the "open" mode and "plasticity" of plant development (*4*). At first glance, the plant body grows by the addition of new structures from so-called primary meristems located at the opposite ends of the body axis. However, recent studies indicate that the primary body pattern is actually generated in the embryo and that the meristems are just terminal elements of the embryonic axis (*5*). After bisection of the embryo, the upper half can regenerate a full embryo including the root meristem, which thus behaves like other, nonmeristematic pattern elements in this assay. This observation also implies that the primary body pattern is established at an earlier stage of embryogenesis. Although pattern formation itself cannot easily be studied experimentally because of the small size of the early embryo, the genetic approach is not limited in this way. Mutational "dissection" only requires that relevant genes mutate to cause diagnostic phenotypes that deviate from the normal pattern.

The primary body pattern of higher plants as laid down in the embryo is best illustrated in the structurally simple seedling, which is remarkably uniform across species (*6*). Along the single axis of polarity, which is to become the main axis of the plant, four distinct pattern elements can be recognized. These are, from top to bottom, the epicotyl including the shoot meristem, one or two cotyledons, the hypocotyl, and the root including the root meristem. Thus, the meristems arise as terminal elements of the apical-basal pattern in the embryo. A second pattern consists of the main types of plant tissue: epidermis, ground tissue, and vascular tissue. These elements are arranged in a radial fashion, with the epidermis at the surface and the vascular tissue in the center.

The mechanisms by which the seedling pattern is generated during embryogenesis are unknown (*6*). Thus, the genetic approach has to perform two functions: (i) it must dissect the process of pattern formation by identifying mutant phenotypes that define different aspects or steps and (ii) it must characterize molecularly the genes thus identified. These goals can only be achieved in a plant species such as *Arabidopsis* that allows large-scale screening for embryonic pattern mutants as well as pursuit of the phenotype-to-molecule strategy.

Mutations causing embryonic lethality have long been known in both maize and *Arabidopsis* (*7*). It is not clear, however, whether pattern formation is affected in these mutants. More direct attempts have recently been made in *Arabidopsis* to identify genes involved in embryonic pattern formation on the basis of their mutant seedling phenotypes. This approach has been called the "*Drosophila* approach" because of its similarity to earlier work in the fruit fly (*8*). The large-scale screens for embryonic pattern mutants in both *Drosophila* and *Arabidopsis* were based on the assumption that genes directing pattern formation are not involved in general cell processes. This assumption implied that in *Arabidopsis* mutations in patterning genes cause diagnostic seedling phenotypes, such as specific changes in the body organization, without interfering with the completion of embryogenesis (*9*). The strategy has yielded several mutant alleles of a small number of genes with very specific pattern defects (*10*). What has been learned about pattern formation in the plant embryo from the analysis of such mutants?

First of all, the identified genes act very early in embryogenesis, possibly at a stage when the embryo consists of only eight cells. Thus, early events have a long-lasting effect on pattern formation. Second, formation of the different tissues does not require apical-basal polarity. Thus, pattern formation along the axis of polarity and formation of the radial pattern are two separate processes. Third, some genes appear to act in specific spatial domains. For example, the apical-basal axis may be initially partitioned into only three regions: the apical region includes the primordia of both the shoot meristem and the cotyledons; the central region gives rise to the hypocotyl;

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