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The Role of Space Science in Graduate Education[1]

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WHAT IS SPACE SCIENCE?

Space science may be defined as the study of the behavior of matter on a cosmic scale. By this definition, it would include such diverse topics as astronomy, astrophysics, cosmical electrodynamics, aeronomy, planetology, cosmogeny, and exobiology. Space science is directed toward answering some of the most fundamental questions that man can ask – questions about the origin and history of stars, planetary systems, the universe, and even life itself. How do stars and planetary systems form? What is the basic development and structure of planetary atmospheres? What causes the aurora? How do plasmas behave on a cosmic scale? How do life forms develop on a new planet?

In the traditional departments of physics, chemistry, and engineering, laboratory studies that aid our understanding of the behavior of matter are made in the fields of nuclear physics, atomic physics, solid state physics, spectroscopy, etc. The knowledge gained in these studies useful in space science, but the research to gain this knowledge is not considered part of space science unless applied to large-scale phenomena. For example, the study of stellar interiors involves a detailed knowledge of many complex nuclear reactions; the application of the knowledge of nuclear reactions to obtain a fundamental understanding of the structure of stars is considered a branch of space science.

The vigor of a field of research is largely dependent on the quantity of related experimental and theoretical work being performed. For example, although a promising start toward a theory of geomagnetic storms and auroras was made by leading physicists between 1850 and 1900. The swing toward the present emphasis on microscopic physics began in 1896 when Rontgen announced the discovery of X-rays. X-ray phenomena permitted direct experiments so that theories could be checked and the traditional interplay between theory and experiment could be maintained. Because geomagnetic and auroral theories could not be tested, however, competing theories flourished like competing philosophies, and these fields stagnated.

With the recent availability of the rocket, space research has gained new strength. The rocket provides a spectacular research tool with which direct observations of the behavior of matter within the solar system can be carried out. Knowledge gained from such observations can be generalized and extrapolated throughout the universe. Just as the availability of large telescopes opened research opportunities in astronomy or as the cyclotron gave impetus to nuclear physics in the 1930's, within the past decade the rocket has given space science a new freshness and vigor.

THE FUTURE ROLE OF ROCKET-BORNE EXPERIMENTS

Space science has as its goal the exploration of the entire physical universe. Thus it is not tied to the immediate results of rocket measurements of near-Earth phenomena. Rather, rocket experiments reveal certain laws governing the behavior of matter throughout the universe that cannot be confidently or unambiguously inferred from laboratory experiments. These laws can be applied elsewhere in the universe with reasonable assurance of their validity.

Laboratory experiments have not, for instance, been of primary importance in adding to our understanding of astrophysical plasmas. However, by using the solar system as a laboratory, the space scientist has acquired the necessary environment for astrophysical plasma studies. The scale of the solar system is large enough to exhibit important phenomena of universal applicability; the measuring probe (the spacecraft) is generally small compared with the size of the phenomenon to be measured and therefore does not perturb it; the interplanetary and magnetospheric plasma can be treated as a collisionless plasma because its density is sufficiently low; and the plasma pressure is, in many cases of interest, greater than the magnetic pressure, thus adding an important range of plasma and field parameters not covered in laboratory experiments.

The ability to make direct observations in space has led both to some scientific discoveries and to the resolution of a few scientific controversies. For example, the Van Allen radiation belt, whose earlier existence had not even been suspected, was discovered by means of the third satellite to be placed into orbit. Space probes and satellites with highly eccentric orbits have established such previously controversial hypotheses as the continuous, supersonic solar wind and the collisionless hydromagnetic shock.

One of the most interesting and important problems related to the solar wind is that of the aurora. The aurora is caused by energetic particles (principally electrons) bombarding the upper atmosphere at near—polar latitudes. These electrons have somehow been accelerated by the solar wind. The acceleration mechanism appears remarkably efficient; during a large magnetic storm, approximately 1% of the solar—wind energy flux that strikes the outer part of the Earth's magnetic field appears in the auroral electrons. Even though we can define all the input parameters (solar wind and magnetic fields) and output parameters (auroral electrons) within a factor of 2, there is no accepted theory describing the basic mechanism whereby solar-wind energy is transferred to auroral electrons.

It is an understanding of the auroral acceleration process that holds the greatest promise for immediate astrophysical application. Throughout the universe there are relatively confined regions containing electrons that have been (and are being accelerated to high energies. These electrons are observed through their various electromagnetic radiations (radio, visible light, and X-ray). Once the auroral acceleration process is understood we will be in an excellent position to generalize this knowledge to other plasma. field systems, for example, the radiation belts of Jupiter, the Crab Nebula, radio galaxies, and perhaps even quasars. If we cannot understand the relatively well defined auroral problem, it is unlikely that we can understand similar physical processes occurring at astronomical distances from us.

Other such research, for example that related to planetary system formation, could be cited. The point to be made is that as long as man wishes to explore and to understand the universe, he will need as much direct observational evidence regarding the behavior of matter on a cosmic scale as he can obtain. The rocket provides a means whereby the solar system can be used as a laboratory for cosmic research. As with the optical telescope, the usefulness of the rocket as a research tool will grow rather than decrease with time.

SPACE SCIENCE AND GRADUATE EDUCATION

It would be difficult for any university to have a strong graduate program in the physical sciences without including several of the fields listed under space science. The advantage of including most of these fields is that space science calls attention to the universality of the laws of nature. It might be said that space science gives laboratory science the added dimension of universal applicability.

In approaching the subject of the proper role for space science in graduate education, I will take the narrow but easily defensible view that education is the only proper business for a university. Everything a. university does should be justified in terms of its educational function. Research and community service, for example, should either be made part of the university's educational program or not be undertaken. Research in space science should then be related to the purpose of graduate education.

A good description of the relationship between research and graduate education has been given by *Booker* [1963]:

> At the conclusion of an ideal undergraduate education, a man's brain works well. He is convinced, not that he knows everything in a particular field, but that he stands a reasonable chance of understanding anything that someone else has already understood. Any subject that he can look up in a book he feels that he too can probably understand. On the other hand, if he cannot look it up in a book, he is uncertain what to do next. This is where graduate education comes in. Unlike the recipient of a bachelor's degree, the recipient of a. doctor's degree should have reasonable confidence in his ability to face what is novel and to continue doing so throughout life.
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> There are, of course, many ways of learning to face [novel] situations with confidence. If this is done in a. university, what is the principal technique available? The answer, of course, is research. There is a.

contrast between research in a university and research in industry or government. In industry or government, research is itself the objective, or is the immediate objective in a series of objectives. On a. university campus, research is the principal means for developing the minds of doctoral students.

In a university, research is the primary tool for graduate education. If we wish our programs for graduate education to sparkle, to be intellectually stimulating, to be of high quality, the research on which these programs are based had better demonstrate such qualities. Space science has these qualities because of the nature of its penetrating questions regarding the most fundamental aspects of the solar system, the galaxy, and the universe. (And let us not completely discount the excitement; generated by the 4th of July aspect of the rocket—space science's newest major research tool.)

STARTING A UNIVERSITY SPACE SCIENCE PROGRAM

Universities have generally been slow to move into the new areas of space science opened by the availability of the rocket. Although they have (until very recently) received strong financial support from NASA, most of the money was spent expanding and supporting the pre-NASA research programs. Thus, some of the more traditional university work in cosmic ray physics, astronomy, chemistry, mathematics, etc., benefited. However, scientists in government and industrial laboratories have carried out the bulk of the most exciting space research using rockets and satellites. While there are notable exceptions that spring to mind (e.g., the work of Van Allen and his students at the University of Iowa), the small relative quantity of university space research can be judged by looking at the institutional by—lines of papers published in journals such as the *Journal of Geophysical Research* or *Planetary and Space Science*. In 1967, the ratio of American university bylines to governmental and industrial laboratory bylines in these journals was about one to one. This is contrary to the research tradition in the United States, as may be confirmed by looking at the institutional by-lines of papers in journals such as the *Physical Review* or the *Astrophysical Journal* that publish mainly on subjects that were fashionable before 1958 (i.e., pre-NASA). In 1967, the ratio of American university by-lines to governmental and industrial laboratory by-lines in these journals was about three to one.

A natural question at this point might be, 'Why?' If space science is really as interesting as I have stated, why are universities apparently so disinterested? Why aren't more universities engaged in graduate research programs that take advantage of the insights and the opportunities provided by data being obtained by spacecraft? The answer, I believe, is simply that university administrations have not exerted leadership in this direction. University administrators very wisely look to the individual faculty members to determine the course of their research. For this reason, however, university research tends to drift. Usually a generation is required for a new field of research to become strong at a university. When a promising new, but very different, research tool such as the rocket appears, the normal course of university research can be altered in much less than a generation if the university administration provides leadership and guidance. It is surprising that, in essence, all that need be done is develop a plan that calls for the establishment of a significant space science program.

For example, if a university thought it desirable to have, say, a strong space physics program, the university administration could either establish a Department of Space Physics that could develop to some predetermined size of faculty and student body, or establish a Laboratory of Space Physics within the Physics Department. In the latter method, the Director of the Laboratory should have a firm plan for growth that is satisfactory to the rest of the Department. The first plan would probably be the easiest to implement since a high degree of cooperation between specialized interests would not be required. Then, once the Space Physics Department had grown to its programmed size, it could be merged with the Physics Department.

The space science effort must be an identifiable part of the educational program of the university. Schemes to establish space science programs at a. university that will not work well are, for example: (1) to form a committee to coordinate the small and sometimes unrelated space research efforts that are spread over several separate departments, or (2) to place one or two junior space-science faculty in an established department and 'wait to see what develops.' The first scheme will falter because a committee is congenitally unable to exert leadership when it is required. It is difficult for a university committee to be identified as an educational arm of the university in the same sense as is a department. In the second scheme, little will develop because the other faculty, more senior and experienced, will usually be reluctant to see a new (and, in their view, perhaps strange) line of research get more than its proportionate share of the available resources of the university (i.e., building space and faculty appointments).

THE COST OF A GRADUATE SPACE RESEARCH PROGRAM

In order to be effective, a. space research program must be broadly based. Unlike the classical forms of laboratory science, where several variables are under the control of the experimenter, the space scientist is a helpless observer of a large and complex system with many internal interactions that make the separation of variables extremely difficult. Specialization should be avoided. To study only, say, energetic particle radiation in space without studying plasmas and magnetic fields in space is rather like a medical school teaching only the function of the liver. A space research program should cover as many related areas of space science as possible in one laboratory so that interactions can be fully appreciated and exploited.

The cost of a broad program that includes experimental work in all-important areas of space science would be so high as to be unfeasible. It has been pointed out that it will be increasingly difficult to justify growth in university research if it is not an essential part of graduate education [*Pitzer*, 1967]. The cost for a space hardware program is now running at about $400,000 per Ph.D.[2] This is far higher than the $150,000 per Ph.D. proposed by *Pitzer* [1967] as a reasonable basis for government funding for 'little-science' where no unusual expenses are involved. Although it is probably impossible to keep the cost of a space hardware program this low, some effort should be made to approach a level of $100,000 per Ph.D. for experimental theses.

A possible solution is provided by the National Space Science Data Center.[3] This Center (NSSDC) was established by NASA to further the use of data obtained from space science investigations. As such, it is responsible for the active collection, organization, storage, announcement, retrieval, dissemination, and exchange of data received from satellite experiments, sounding—rocket probes, and high-altitude aeronautical and balloon investigations. In addition, the Data Center collects correlative data, such as magnetograms and ionograms for onsite use at NSSDC in the analysis and evaluation of the results of space science experiments.

The amount of data stored in the Center is large; it will soon become enormous, as may be seen from the information shown in Figures 1 and 2 [*Naugle*, 1968]. A feasible mode of operation for a university might be to have one or two space experiments conducted on campus while related research utilizes data available through the National Space Science Data Center. The cost per Ph.D., using data stored in NSSDC, should be relatively low. Experiments initiated and carried out on campus are necessary to provide some experience in handling spacecraft hardware and obtaining raw data. I believe it would be difficult for a group to use only NSSDC data without having had any first-hand experience in experimental space science.

SUMMARY

As science progresses, it is certain to become more unified. Space science, covering the broadest aspects of the behavior of matter on a cosmic scale, exerts a. unifying effect on science and will therefore become of increasing importance for graduate education. The establishment of a space science program on a university campus requires hardly more than a. plan to do so. The program, tied to graduate education, can be kept relatively low in cost by utilizing, in part, the data available in the NASA National Space Science Data Center.

[1]Based on a paper presented at a colloquium at the University of Denver on 'The Effects of a National Space Program on Universities,' April 4-5, 1968.

[2]This estimate is based on my experience with the Department of Space Science at Rice. The number quoted does not include the cost of the rocket or the launch operation.

[3]For more information on the National Space Science Data Center, write NSSDC, Goddard Space Flight Center, Code 601, Greenbelt, Maryland 20771.

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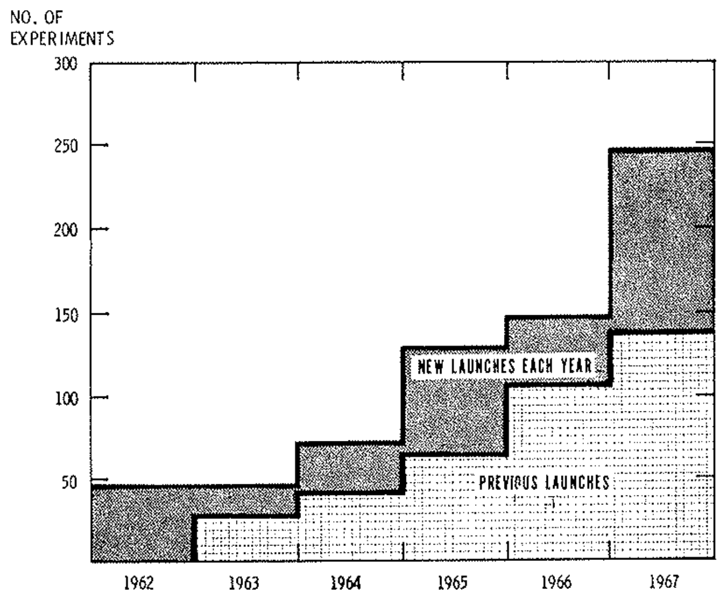

Fig. 1. Number of satellite experiments producing data as a function of time. The increase of data coming from earlier launches is due to the increase in reliability and longevity of the spacecraft and its various subsystems [*Naugle*, 1968].

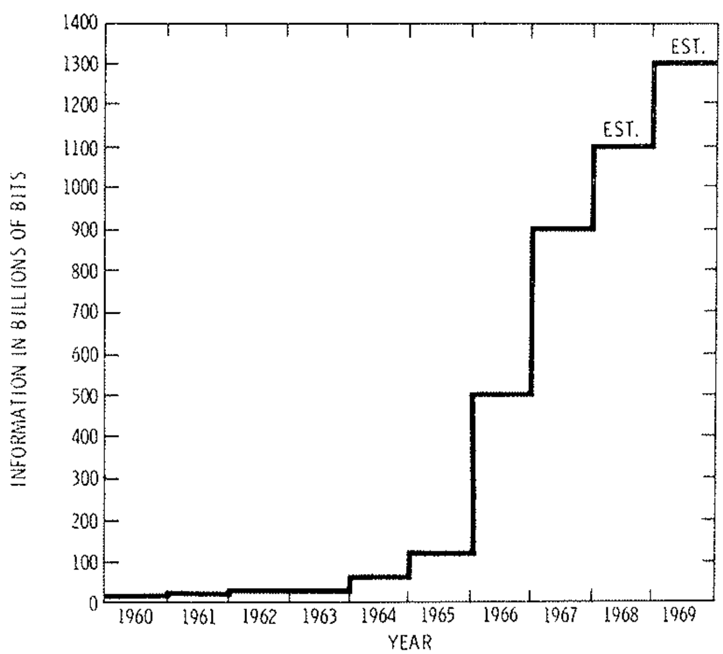

Fig. 2. Quantity of scientific data available from satellites as a function of time [*Naugle*, 1968].