
THE PRESENT AND FUTURE OF
ASTROPHYSICS AND ITS EFFECTS
ON INDUSTRY IN COLORADO

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I am speaking to you under a provocative title. Let me disarm you right away by stating that astrophysics—thought of as simply a branch of astronomy—has a negligible direct effect on industrial activity in Colorado, the volume of which is a $1 billion business. Twenty-five years ago the very suggestion that astronomy had some economic importance would have been cause for horselaughs. The American Astronomical Society membership in 1938 was very small. The only way an astronomer could find employment was in teaching, or possibly a very modest stipend at one of the observatories which depended entirely on meager support from philanthropy. One might have asked the question, "How could industry help astronomy?" Certainly not "How does astronomy support industrial growth?"

But times have changed; astronomy has changed; the patterns of industrial growth have changed; and the attitude of the public as reflected in government toward the purposeful nurturing of science for economic purposes has changed. I believe there is now an important but indirect relationship between the quality of universities, particularly in applied sciences, and the growth of research-oriented industry in the region.

First, let me digress to comment on the changes in the science of astronomy itself. Astronomy is basically a descriptive science concerned with observations of the heavens with telescopes and other instruments. Astrophysics is essentially the interpretive branch of the subject—the application of the full powers of physics, chemistry, and mathematics to a basic understanding of the universe external to the earth. Thus, you might suspect that as astronomical observations become more and more sophisticated and the tools of physics more powerful, the distinction between astrophysics and astronomy becomes relatively meaningless. Science in almost all fields has advanced beyond the state of exploration, discovery, and empirical classification to a new stage of analysis, understanding, and prediction, and hence to applications in other fields.

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Even in the observational sciences it is now most profitable to attempt first a basic theoretical understanding of the large body of extant knowledge, and then plan programs of observation based on the prediction of new phenomena, gaining knowledge from the observations about the basic physical mechanisms involved. Approached this way, astronomy becomes astrophysics. And astrophysics spills over the boundaries of astronomical phenomena and becomes a field of applied physics, ready for application to any laboratory problem. The heavens become one vast laboratory, waiting to be described to satisfy our curiosity about the universe we live in, but also available to test and extend our knowledge of basic physics, and finally suggesting to us new ways to apply this physics on earth to man's purposes.

An example: When the physicist Hans Bethe (or should I call him an astrophysicist?) understood the details of the energy generation of the sun in terms of thermonuclear fusion of the elements, the race to apply thermonuclear fusion to the production of energy for man was on. The practicality of the principle had been demonstrated, so to speak, even if on a rather cosmic scale. And where does the country turn for scientific manpower to apply to this effort to achieve controlled fusion power? Many of the ideas have come from the observatories. Lyman Spitzer, for example, Professor of Astronomy and Director of the Princeton Observatory, created the Matterhorn project, a plasma physics laboratory in Princeton devoted to this very practical and economically oriented goal. The $40 million C-Stellerator, only one of several thermonuclear machines at the Forrestal Research Center in Princeton, dwarfs in cost our biggest optical telescope, the 200-inch one at Palomar, which cost less than $7 million including building and roads.

The entire AEC program of research on thermonuclear fusion power, Project Sherwood, involves an annual budget of $24 million. In addition, large amounts of private capital are being invested. This entire effort might be called applied "laboratory astrophysics," for it involves the attempt to compress and hold in the laboratory gases which have been heated to conditions which prevail only in the atmospheres of stars.

Thus, if we regard astrophysics in terms of the applications of the astrophysical sciences—those scientific areas for which the training of a modern astrophysicist is sound preparation—we find a very impressive amount of activity in Colorado, with economic consequences which are not negligible. Although I am not as well acquainted around the state as I would like to be, I could name the Martin-Marietta Corporation, Ball Brothers, Kaman Nuclear, Beech Aircraft, the National Bureau of Standards Central Radio Propagation Laboratory, the High Altitude Observatory and National Center for Atmospheric Research, the Joint Institute for Laboratory Astrophysics. Each of these organizations is an example of a laboratory doing many hundreds of thousands of dollars—in some cases many millions—worth of research annually in fields related to astro-
physical sciences. Their work embraces rocket and satellite exploration of space, research on communications in space by radio waves, the analysis of military data on effects of nuclear explosions in space, the relationship between solar storms and earth weather, as well as research in astronomy and astrophysics for their own sake and the related fields of gaseous electronics, plasma physics, and aeronautical sciences.

Many of the companies named above are heavily involved in the space effort. Professor William Rense at the University of Colorado is a pioneer in rocket research in astronomy; he still leads the only successful university group which has studied the ultraviolet spectrum of the sun from rockets. Ball Brothers Research Corporation was founded by students from this group, and NASA has recognized Professor Rense’s contributions to space science both through continued research support and a grant to construct a new Laboratory for Atmospheric and Space Physics at the University of Colorado. But all of this talent, industrial and academic, is broadly applicable outside space applications—and the students trained are prepared for much broader fields of application. It is in this respect that these space activities constitute an important economic resource for Colorado.

The University of Colorado effort, which helps to support this growing commercial and government effort in astrophysical science, includes not only an intimate involvement with four of the laboratories just named but three academic departments which are training students through curricula unique in depth and breadth in this country; the Departments of Physics and Astrophysics, Aerospace Engineering Sciences, and Astrophysics and Atmospheric Physics. In terms of numbers of graduate students in astrophysics, I believe the University of Colorado ranks third in the country and is still growing.

For the moment, let me sidestep the question of the economic effect of this work in astrophysical sciences and the question of how much additional business it attracts to Colorado. What I wish to show you is that you can no longer identify an astrophysicist by his beard, or his isolation in an observatory on a remote mountain. You will find him applying physics to a problem which excites him. It may have to do with the light of some remote and curious star, which light has been traveling in our direction since the dawn of history. But you may find him working with meteorologists on the effect of solar activity on weather, applying astrophysical techniques to the measurement of temperatures of industrial plasma devices, or involved in any number of other engineering applications.

Thus, the history of technology has evolved from a single discipline of natural philosophy, through subdivision, into ever-increasing numbers of isolated disciplines until the number of subdisciplines becomes so numerous that the demarkation between them becomes meaningless. All of the observational and applied sciences now share a universality
in that they involve the wide-ranging application of mathematics and physics to the entire range of problems of concern to man.

By now I hope you see my line of argument emerging. If we make the hypothesis, for the moment, that the vigorous and imaginative application of basic science to engineering problems has a strong, stimulating effect on industrial growth in advanced technological fields, then there is indeed a connection between the economic health of the state and the quality and vigor of its programs in astrophysics and every other branch of applied science.

Later I will come back to a brief discussion of Colorado's special problems and opportunities, but first let us examine the general economic hypothesis that university research and engineering directly stimulate industrial growth.

Perhaps we do not need to demonstrate this causal relationship. This is an article of faith in this country. Perhaps the proof lies in statistics showing the ever-increasing involvement of industry in the manufacture of new products which are the result of recent research. Perhaps it is the public demand for new ideas and new things which is significant, rather than the mere fact that the inventions were available. Certainly, innovation which leads to higher productivity at lower cost does bring a more favorable competitive position. Indeed, at times we have been almost embarrassed by our native skill in the utilization of science in industry. In 1954 Donald Price, in his book Government and Science, expressed his concern as follows:

The massing of scientific research for attack on military problems has its industrial by-products. In these fields the tremendous military research program is probably pushing our industry farther and farther ahead of its competitors, at a time when the most difficult economic problems of the free world arise because we can produce more things more cheaply than our allies.

Many American businessmen in competition with the Japanese and Germans wish this were true. But all the more reason why we should look carefully at the goose which has been laying our golden eggs to see that we are not neglecting her.

Our dinner speaker of last night, the Honorable J. Herbert Hollo- mon, Assistant Secretary of Commerce for Science and Technology, is concerned that there are not enough by-products of military, space, and atomic energy research which are useful to civilian technology to keep the civilian economy in a strong competitive position with respect to other advanced nations with smaller military and space commitments. This is a particularly acute problem because the military space and AEC programs consume almost all of the available scientific manpower and drive up its cost. It is certainly true that the development problems which face the Department of Defense and NASA are often so sophisti-
location of industrial research and development facilities? Perhaps highest on the list is the existence of a community advanced in its scientific, business, and cultural outlook, with a reservoir of human talent of all kinds but specifically in the applied sciences and engineering. The university is our most effective, indeed, almost our only source of this precious raw material of the research industry.

This community needs four technical components: industrial research and production involving advanced technology, applied research and engineering, basic research, and higher education. All four will be found in Palo Alto, in Princeton, on Route 128 outside Boston, in Pasadena. But the size of these activities is not so important. It is quality that counts, and in the case of the three nonindustrial components how farseeing and original in outlook they are.

It is also important not to minimize the requirement for a high level of cultural activities. The university which cannot support its Department of Fine Arts will have difficulty becoming a center of attraction for managers or scientists from New York or Boston, or for that matter keeping at home the native Colorado talent which it is our primary job to educate.

For comparison let us take a look at another section of the country with some of the same problems and opportunities as Colorado, my native state of North Carolina. Although in 1955 North Carolina's average personal income was somewhat lower than Colorado's, the state is now more industrially developed than Colorado. Nevertheless, North Carolina faces economic problems because of the commitment of most of the people to textiles, tobacco, and agriculture, all of which are in relative economic decline. During the period 1956-58 the economic future of the state was studied. Under the leadership of Governor Luther Hodges, now the Secretary of Commerce, the Research Triangle Foundation was created to advance a plan which would attract to the state the type of economic activity the state desired. This plan would take advantage of one of North Carolina's greatest assets: three universities located within 30 miles of each other. They are Duke University, the University of North Carolina, and North Carolina State University. The former executive secretary of this planning group is our last speaker at this conference, George L. Simpson.

They asked themselves this question: What industry do we want? George R. Herbert, President of the Research Triangle Institute, answered the question this way in an address in 1960:

We have demonstrated that the important growth industries are the technically based—or research-based—industries. In 10, 15, or 20 years a major portion of this country's manufacturing plants, and a major percentage of workers, will be engaged in producing products which do not exist today. The future of our state, and region then, depends on our ability to expand or diversify our
cated that it is hard to see much benefit accruing to the textile or mining industry. And yet the solution of these sophisticated problems depends so heavily on strong and expanding scientific research and higher education in our universities that the Department of Defense, AEC, and NASA have spent enormous sums in the purchase of research in the university community. In my opinion it is here—in higher education—where the economic payoff lies and where we will find advanced research designed to support the nation's entire effort in science and technology.

The support of higher education depends, in the long run, on local and state resources and on the assistance of the federal government; for example, through the National Science Foundation. The support through purposeful research and engineering in the fundamental area of the science of measurement is the job of the National Bureau of Standards of the Department of Commerce. Through a number of examples, of which the Joint Institute for Laboratory Astrophysics is one, the Department of Commerce recognizes that, where the government can meet its responsibilities more effectively and economically by collaboration with universities, this collaboration can further cement the close relationship between higher education and university research on the one hand, and the long-range growth of business based on advanced technology on the other.

The federal government's purchase of research and development amounts to about 2.5 percent of the gross national product. Thus, this $13 billion does not represent a major expansion in the G.N.P. It is the indirect effect of the relatively small fraction spent on the training of new talent and generation of new ideas and better measurement tools for civilian technology which will contribute to the growth of the whole economy. Of course, if we look at Colorado alone, where in 1962 only 90,000 workers were engaged in manufacturing, the economic effect of direct federal support of space or military research is more important. Still, the state will benefit from a diversified and consumer-oriented industrial base which is not too dependent on the changing demands of national defense and space goals.

As far as mass-production industry is concerned, providing employment for tens of thousands of people, it is not obvious to me that the attraction of small research companies leads to the creation of sources of mass employment. But neither is it obvious that this is a desirable goal—many of the eastern states are eager to relieve their dependence on heavy industry by encouraging diversification based on advanced technology.

American industry adopted a national outlook long ago. Research, raw materials, production, and marketing facilities may be in widely different parts of the country—each located in a region appropriate to its particular requirements. What are the factors which govern the
industrial base by attracting a greater share of the new research-based industry in the 1960's.

He counted as the state's greatest assets in this effort:

... a well governed state, equitable legislation for industry, good schools, outstanding universities and a belief in education as the base for our future.

Then what did they do? After raising $1.8 million from public-spirited citizens and businesses and adding direct grants of $500,000 from the state legislature, a 4,600-acre research park was purchased and the Research Triangle Institute established. This institute is a wholly owned subsidiary of the three universities, having its own permanent staff, many of whom are adjunct professors at the universities, and utilizing the faculties for consulting. About $2.5 million per annum of research is carried on in the institute. In addition, the foundation has encouraged the development of the adjacent industrial park which now houses the $5.5 million Chemstrand Research Center, a $600,000 U.S. Forestry Sciences Laboratory, a small Corning Glass laboratory, and soon the headquarters and laboratories for the American Association of Textile Chemists and Colorists.

These dollar figures are not the measure of success of the North Carolina program, for simultaneously they are upgrading education and trying to attract business by other means. The coupling with education is particularly interesting. One unique aspect of the research institute is that, when the institute is well established, at least a portion of the revenues from its research business will return to the three universities to be used as an addition to their available research funds.

This North Carolina program is in a sense a pace setter, for it was created as the result of a deliberate decision in the state that such a program was needed for the long-range good of the state, following an examination of the question posed at this conference: it was not a target of opportunity, so to speak. Furthermore, it is well diversified and not exclusively tied to any one type of business customer. Other southern states have acted to take advantage of large programs of NASA. The University of Alabama Research Institute and the adjacent Huntsville Space Research Park were launched by the university and the city of Huntsville, and though only one year old have six major aerospace research laboratories under construction or in operation. These projects are much more vulnerable to large changes in space and military requirements.

But Colorado, which has some tremendous intrinsic advantages over these southern states, has already taken steps which are in my view more soundly based than the Research Triangle idea and, accordingly, is faced with an enormous challenge.
First, Colorado is tilling new soil. Not faced with a large and declining industry to the degree some other states are, Colorado has the spirit of a young state confident in the future. It is further spurred by the realization that the state, whether it likes it or not, is in a leadership role for the Rocky Mountain region. Colorado cannot look back, because the rest of the country is convinced that here is where opportunity lies even if some Coloradans lack this confidence. After all, the hundreds of thousands of people who are moving into metropolitan Denver all came from somewhere else.

Next, Colorado's universities, while rooted in our pioneer past, are faced with new challenges which have forced the state during recent years to realize that major new investments in higher education are essential. First, the population influx and economic upsurge of this region require a response from the universities. The rest of the country insists, if you like, that the Denver region shall be a center of education and culture which stands, between Chicago and the Pacific, as a focal point for the development of all the mountain states. The long-term Ford Foundation support to the University of Denver attests to national interest in support for a private university in this region. In Boulder, the location of the High Altitude Observatory, the National Bureau of Standards Boulder Laboratories, the National Center for Atmospheric Research, and the Joint Institute for Laboratory Astrophysics is the result of decisions on a national level that Boulder provides the environment which can produce quality. The university is the key element in this environment.

What should we do as the next step in Colorado?
First, the state—and I mean its citizens as well as government—must look at the state's balance sheet, capital assets, and future growth prospects, and be prepared to reinvest a reasonable fraction of the profits in the future. And its future rests on education and diversified industrial development—the two being closely linked. This, unhappily, involves taxes but it also involves the direct participation of the state's industrial community and citizenry in the long-range investment for future growth. Specifically, the universities, private and public, must earn and win the support of the state which is needed in order to keep up with the demands for improved quality as well as increasing enrollments. The state has struggled for many years, with great progress, to improve the quality of its universities by hard work and expenditure of funds. But I believe that many citizens of the state do not realize that once a university passes a certain critical level of quality—quality of faculty, students, and facilities—suddenly the market for academic improvement switches from a buyer's to a seller's market. At this point the justifiable demand on state resources becomes very great, because it is poor economy to slow down the rate of progress just at the point where great progress becomes easier to achieve. I believe the University of Colorado is at this point.
Secondly, in the area of advanced research and technology the state should encourage and take advantage of sound programs of cooperation between federal, state, and local organizations. In the making of grants for scientific and educational purposes, it is common for the granting agency to require that the monies be matched locally in some ratio. This insures that the institution receiving assistance feels an adequate degree of long-term responsibility for the soundness of the program. I believe that much can also be achieved in matching talent. It is in this way that the Joint Institute for Laboratory Astrophysics comes by its first name, and both the Department of Commerce and the University of Colorado are the richer for it. Each can do its job better and cheaper and, in addition, a center of excellence in laboratory astrophysics is created with sufficient strength to influence favorably the quality of research in this field around the world.

The scientific community in Boulder is lively and exciting and comprises laboratories which are wholly federal, wholly state, wholly private but with federal, mixed federal and state, mixed private and state support. There could well emerge more complicated combinations. Scientific visitors to Boulder often leave town with their heads buzzing, confused about the organization (or lack of it) but impressed with the vitality of the research and the teaching. This is just as it should be. But it provides great opportunities for imaginative, concerted leadership by university, state, and business leaders, to use the talents and assets and common goals of all of these groups to a common end—the development of a scientific community with the range of teaching, basic research, and applied research groups which will provide the fountainhead for industrial activity in advanced technology.

Third, we must remember that the university provides an essential link in the effect of basic and applied research on industrial growth; teaching and research should not be separated. It is very rare that a research institute which is not an intimate part of a university, responsive to university control and populated with students, is able to maintain high quality for a long time. This is particularly true when the institute depends primarily or solely on contracts, and when it gets very large. The Research Triangle Institute in North Carolina is proud of the fact that it has $2.5 million in business this year. The Stanford Research Institute is, I suppose, very much larger still. But neither is on a university campus, neither has a tenure staff in the academic sense, and both are dependent on contracts. The work they do may be of very high quality and of direct economic benefit. But the real dividends come from the students who are trained in advanced research and from the small numbers of pinnacles of scientific achievement—usually scaled by people who are part of or closely associated with a university.

In this respect the University of Colorado started out on the right foot. The High Altitude Observatory was established as part of the
University of Colorado and located on the campus. The NBS Boulder Laboratories, almost adjacent to the campus, are closely linked to the university through professors ad joint on their staff. The Joint Institute for Laboratory Astrophysics is a partnership of the University of Colorado with NBS, also located on the campus, and is integrated into existing university academic departments. Professor Rense's Laboratory for Atmospheric and Space Physics is a wholly university operation for space research supported by government contracts and grants. The Denver Research Institute and Colorado State University Research Foundation are properly integrated into those universities.

The benefits to the state of this integration of advanced research laboratories into the universities far outweigh the substantial costs to the state which are required to permit the universities to do their share in the cooperation.

Finally, there can be no compromise with quality and no tolerance of complacency. You cannot talk about trying to achieve for Colorado what has been done in Palo Alto unless you are prepared to see the University of Colorado and the other schools compete with Stanford in quality. You will not lure business from Route 128 unless the availability of technical brainpower, the business and cultural environment here, competes with Boston. Whether we like it or not, we are competing on a national scale. We compete successfully now in isolated areas; we have a long way to go to compete in depth and breadth.