Laboratory ASTROPHYSICS

By Lewis M. Branscomb and Richard N. Thomas

THE development of American astronomy over the last quarter century has been chiefly characterized by the construction of larger and larger telescopes. The size and diversity of those covering the visible spectrum have increased steadily over the period. The radio spectrum has been studied since the war, with telescopes now approaching the size of a football field. Most recently, designs for "space" telescopes, extending the spectral coverage to the far-ultraviolet and x-ray regions, fill the imaginations of virtually all astronomy and "space" departments. The accompanying conceptual investigations have been mainly attempts to understand the evolutionary development of stars and stellar systems—on the one hand, by surveying greater volumes of space in more minute detail, and, on the other hand, by close collaboration with nuclear physics to study the interrelation between possible nuclear-energy sources and stellar structure, along the various evolutionary tracks.

But during the first half of this quarter century, the once-exciting partnership between astrophysics and physics in the spectroscopic diagnostics of phenomena in stellar atmospheres lay quasidormant. In the 1920's and early '30's, this partnership had produced modern spectroscopy and quantum mechanics, as well as our first insight into the structure and composition of stellar atmospheres. In this later period, analyses of stellar atmospheres were fairly routine, seeking information on abundances, while interest in atomic physics was supplanted by developments in nuclear physics.

During the last fifteen years, there has been a rebirth of interest in spectroscopic diagnostics of hot gases, and an associated increase in theoretical and laboratory work in atomic physics. Astronomical interest in a more physically consistent diagnostic spectroscopy has been kindled by theoretical studies of the physical consistency of notions of temperature and nonequilibrium thermodynamics in stellar atmospheres, by similar studies on the effects of observed velocity fields upon the thermodynamic structure of these atmospheres, and by attempts to apply these notions in the analysis of the outer solar atmosphere. Rather than being simply specimens for astronomical taxonomy, stellar atmospheres have again become regarded as physics laboratories, extending the phenomenological range possible in the laboratory.

The developments of modern aerodynamics which produce shock velocities large enough to excite electronic degrees of freedom of the gas, introduce spectroscopy as a diagnostic tool there. The embarrassment surrounding faulty diagnostics of the temperature in the "thermonuclear" plasmas, when early claims of thermonuclear "temperatures" were found premature, has at last brought a strong interest in atomic physics and spectroscopy into this field. Many of these phenomena are studied under conditions such that the distribution functions of local thermodynamic equilibrium are not applicable. Thus they inspire a demand for the atomic cross sections and rate coefficients necessary for detailed computation of occupation numbers, which was not being satisfied in any of the astrophysical institutions.

Fortunately, during this period, a parallel development was taking place in the study of atomic collisions under the inspiration of attempts to interpret ionospheric and aeronomic phenomena by a detailed treatment of nonequilibrium collision processes. Most influential were the theoretical and experimental schools in London and Belfast, where the marriage of atomic-collision theory and upper-atmospheric physics has proved most fruitful since World War II. The growth of plasma physics and fluid dynamics has been heavily responsible for the shift in interest among low-energy atomic physicists toward high-temperature atomic processes rather than toward the low-temperature molecular problems characteristic of upper-atmospheric physics. Technical advances in high-vacuum, modulated atomic-beam methods, and computers have combined with this changing interest to lead the atomic physicist to join the spectroscopists in a natural collaboration with the astrophysicist. Unfortunately much of this development in the field of collision phenomena has taken place out-

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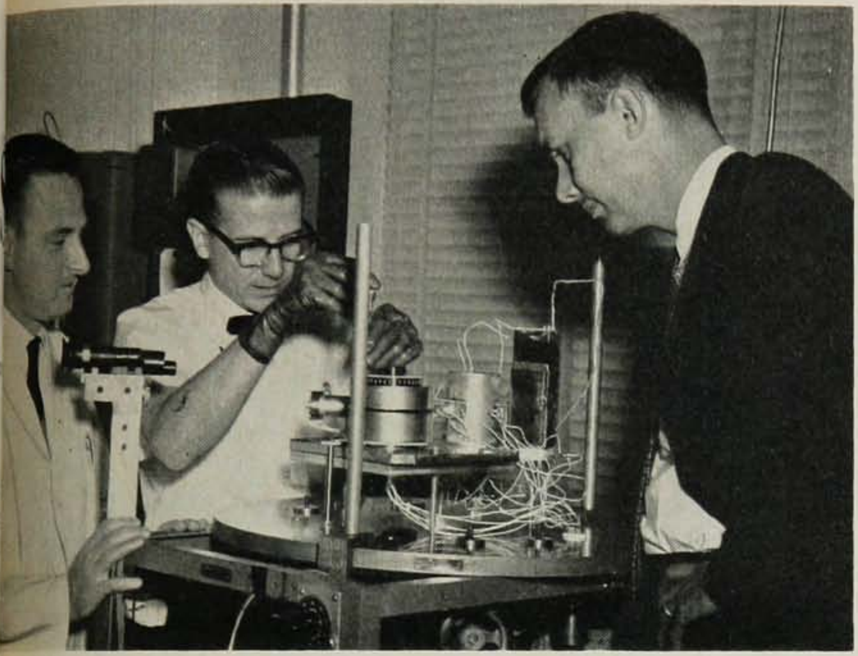

Shown (left to right) in the photograph are Lee J. Kieffer, Gordon Dunn, and L. M. Branscomb of the National Bureau of Standards group in the Joint Institute for Laboratory Astrophysics (JILA). Dr. Dunn is adjusting the scattering chamber with which he and Dr. Kieffer are studying angular distributions of protons from the dissociative ionization of molecular hydrogen. Other members of the JILA staff from the NBS Washington Laboratories are Earl C. Beaty, Peter L. Bender, George Chamberlain, Sydney Geltman, John Hall, and Stephen J. Smith. The Bureau is also represented on the JILA staff by John T. Jefferies and R. N. Thomas from the NBS Boulder Laboratories.

side of the universities, largely because of the trend of interest in physics departments toward nuclear and solid-state physics. Even in universities where active atomic-physics programs have been maintained, they have often suffered an unnatural isolation from the departments of astronomy.

These developments of the last fifteen years might be called the "laboratory astrophysics" of hot gases: the prototype situations occur in stellar atmospheres. Diagnostic spectroscopy is aimed at assessing the physical conditions, studying the physical phenomena, to gain as completely consistent a picture as possible from the astronomical point of view. Emphasis is given to providing a consistent interpretation of observations through the application of both theoretical and laboratory investigations. Of course, new material—especially such as that coming from the rocket ultraviolet observations—provides needed extension of the observational energy range; and the analysis often points up a necessary improvement in the character of the astronomical observations, but primary emphasis lies on laboratory experiment and theory, not new observatories and telescopes.

This same kind of interest in laboratory astrophysics has arisen in other fields of astrophysics. Meteor astronomy, and its close relation to high-speed aerodynamics, particularly the re-entry problem, has been a classic example. The chemistry of the particles in the interstellar medium provides another illustration. But too seldom has the direction of laboratory astrophysics been considered in planning the development of modern astronomy. As mentioned initially, the emphasis has conventionally led toward plans for newer and larger telescopes. The laboratory astrophysics effort usually appears prosaic compared with the glamor of a new observatory, especially one in space.

The Formation of JILA

For some years, the National Bureau of Standards has carried out a program in laboratory spectroscopy and atomic physics. Most recently, it has initiated a modest program in theoretical astrophysics to tie its laboratory work more directly to the needs of the working astronomers. This program has involved collaborative efforts with solar observatories in this country and groups of astrophysicists and atomic physicists in France and England. During the last year, NBS and the University of Colorado have discussed the feasibility of relocating some of the members of this NBS program to bring them in close proximity to the space program in the University of Colorado Physics Department. The aim would be a more systematic research and academic program in laboratory astrophysics, aiming initially, at least, to concentrate on the laboratory astrophysics of hot gases.

On April 13 of this year, the University of Colorado and the National Bureau of Standards announced the formation of the Joint Institute for Laboratory Astrophysics on the University of Colorado campus. The Institute will embody four groups: the laboratory astrophysics group of the NBS consists initially of eight atomic physicists from the NBS Washington laboratories, plus two theoretical astrophysicists from the Boulder NBS laboratories; the second group is formed of faculty members in astrophysics and space physics from the University of Colorado Physics Department; the third group consists of some members of the aerodynamics department of the University; and the fourth group will consist of ten visiting members on temporary (usually one-year) appointments. This last group will be visitors on leave from other institutions, local and foreign, spending a year at the JILA without formal obligations. The permanent staff of the JILA will be small, some twenty-five persons at the senior level, and will come to full strength slowly. The National Bureau of Standards will continue to place primary reliance on its central laboratories in Washington for most of its laboratory work in spectroscopy and related fields.

JILA has commitments in two directions: scientific research and academic training in the field.

Scientific Objectives

The broad scientific objectives of the JILA have been described above. For the first few years the program of the staff forming the JILA will cover three main areas:

(1) Research in basic atomic physics, with an emphasis on those stationary and interaction properties of atoms and molecules needed for a microscopic description of a gaseous ensemble under completely arbitrary conditions;

(2) Research on cooperative behavior of gaseous ensembles of a nature requiring knowledge of the atomic properties, for example, plasma physics, aerodynamic problems involving excitation of internal degrees of freedom of a gas and subsequent radiation, transport problems in weakly ionized plasma, atomic-resonance phenomena such as lasers and optical pumping;

(3) Research in those areas of stellar atrophysics dealing primarily with applications of the physics of (1) and (2) above to problems of astrophysics. Interpretations of stellar spectra will play a major role, particularly emission spectra in the "rocket region" of the spectrum.

In the acquisition of additional permanent staff, the JILA will attempt to insure that breadth in astrophysics and in atomic physics is achieved so that the academic and research program are in no danger of becoming too specialized. Additional staff strength will be sought in stellar astrophysics, atomic spectroscopy, hydromagnetics, atomic theory, and spectral-line formation and broadening.

In astrophysics, the Institute will emphasize theoretical rather than observational work and will concentrate most heavily in these areas in theoretical astrophysics having the closest coupling with low-energy physics. The principal initial emphasis in astrophysics will lie in the areas of stellar atmospheres, gaseous nebulae, and the interstellar medium, but a broad coverage of astrophysics will be encouraged. The approach will emphasize basic physical principles and the physics of the astronomical medium. Although the availability of high-quality observations of the solar spectrum at all wavelengths permits a more detailed and complete treatment than is possible in stellar spectra and suggests a major focus of effort on solar problems, the Institute will vigorously pursue a broad program of investigation of physics of stellar atmospheres under all conditions.

In atomic physics, statistical physics, fluid mechanics, and gas dynamics, the basic physical principles will again be emphasized. In atomic physics, the heaviest

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A prominent role in all this has been played by a gentleman named Kuan-Han Sun, who once worked for us before his interest turned from non-silicate optical glasses to nucleonics. Married one of our x-ray researchers and took her off with him. Lovely gal whose name was Laura McGillivray.

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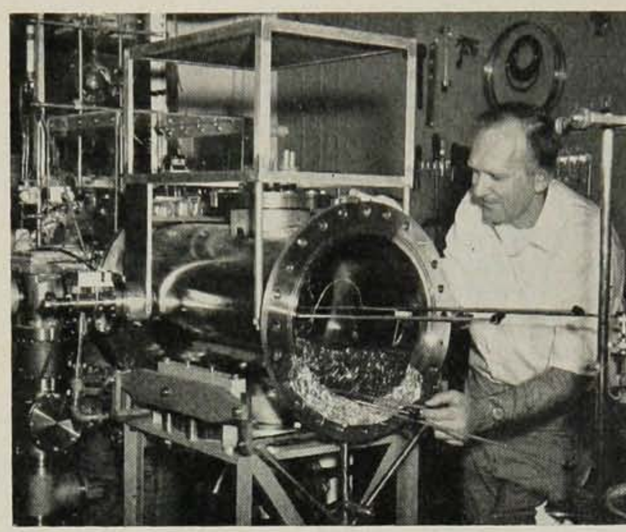
This is another advertisement where Eastman Kodak Company probes at random for mutual interests and occasionally a little revenue from those whose work has something to do with science



S. J. Smith, former chief of the NBS Atomic Physics Section, reassembles his modulated atomic-beam apparatus in JILA laboratory.

emphasis will be placed initially on atomic, electronic, and ionic collision cross sections; on atomic-resonance phenomena and lasers; on ultraviolet and visible atomic spectroscopy; on oscillator strengths and continuous absorption coefficients; and on ionic reaction rates. The objective of the atomic-physics group will not be to determine parameters at the request of astrophysicists (which may occur, but is not practicable in general), but to develop basic concepts and techniques in atomic physics. While gaining greater familiarity with astrophysical problems, the atomic physicist can take advantage of those opportunities that do occur to match a capability in the laboratory to a particular need of the astrophysicist. It is to be hoped that the experimental atomic-physics group will make its greatest contribution to the improvement of theoretical techniques in atomic physics, so that the main production of data for use by astronomers can be done theoretically. Research and the training of students in physics and in astrophysics are equally important and the responsiveness of the work in these fields to astrophysical needs is expected to come about through informal day-to-day contact between staff members of the Institute.

In fluid physics, some examples of problems of great interest to the Institute are radiation-transfer problems, line broadening and relaxation mechanisms, the treatment of the coupling between aerodynamic dissipative mechanisms and the radiation fields through which energy is lost, departures from local thermodynamic equilibrium in shock waves, etc. The primary objectives of the Institute relate to aerodynamics through the area of ultraspeed aerodynamics treated from the microscopic point of view.

Academic Training

The academic training in the areas of interest to JILA will fall in the province of the astrophysics and atomic-physics faculty within the Department of Physics. In addition, members of JILA not holding their primary salaried appointments on the University of Colorado faculty may participate in the academic program in several ways. They may teach undergraduate and graduate courses in physics and astrophysics through appointments as research associates or lecturers. On a basis of greater involvement in the formation of academic policy, some have appointments as professors adjoint in the department. In this manner, the University will enjoy the full and active participation of the entire NBS group, and JILA will partially represent an academic faculty collaborating with the rest of the Department of Physics.

A most important feature of the academic program is expected to be provided by JILA's visiting-scientists program. Not only will the students pursue the customary curriculum of courses in atomic physics, astrophysics and aerophysics, but also they will gain a large part of their advanced training from seminars and personal contact with visiting members, drawn from universities and laboratories all over the world, whose presence will help broaden the experience and interests of the advanced students. Holders of postdoctoral fellowships will also be encouraged to receive further research training at the JILA.

A central objective of the Institute is to provide a significant increase in the number of trained scientists in the field of laboratory astrophysics. Government studies have repeatedly indicated the seriousness of the drop off of training in the more "classical" fields of physics (such as spectroscopy) at a time when spectroscopy is still the most modern and effective tool of astronomy. The above program will utilize the entire staff of JILA for doctoral and postdoctoral training in these areas.

Finally, it should be noted that the new Joint Institute represents a departure from the conventional form of university-government agency cooperation, and a new experiment by the National Bureau of Standards designed to achieve certain specific objectives in a more effective manner than could be done in the central laboratories. Instead of creating a not-for-profit corporation or an arrangement whereby the University acts as a contractor to establish an on-campus institute, the National Bureau of Standards and the University of Colorado have chosen to enter into a partnership, with each supplying part of the permanent staff and each contributing to the cost of the venture. Thus, no new corporate entity need be created, and the project has been put into operation with a much smaller administrative organization than would otherwise be the case. JILA is small and plans to remain small by comparison with the other kinds of research laboratories currently growing up. Yet, at the same time, it provides a comparatively large addition in size to the academic faculty in the area of its work.