PART 5

SPECIAL MEETINGS

DISCUSSION ON THE TEACHING OF ASTRONOMY

REPORT OF MEETING OF THE INTER-UNION COMMISSION ON SOLAR AND TERRESTRIAL RELATIONSHIPS

THE RESULTS OBTAINED FROM RANGER VII

DISCUSSION

ON

THE TEACHING OF ASTRONOMY

Preliminary Report

M. G. J. Minnaert

Astronomy is a science in very rapid evolution. It is no longer limited to celestial mechanics, but concentrates on astrophysics, on the structure of the universe and on its evolution. Many new technical methods have been introduced, including electronic computers, radio astronomy and space research. This rapid, almost explosive, development attracts the greatest interest from the general public, the newspapers, radio, television, and the cinema. We have to investigate the consequences which this new situation must have on the teaching of astronomy at different levels.

The present report is intended only to point out the most important questions and to stimulate discussion. It is based primarily on the answers to our questionnaire, received from 29 countries. Good use was also made of Dr Chamberlain's report on the U.S. Conference on Graduate Education in Astronomy (*Astr. J.*, **68**, 215, 1963), and of Prof. Bok's note on a similar discussion at Sydney (November 1963).

As soon as a world-wide comparison has to be made, we are confronted with the difficulty that the organization of teaching, the degrees, and their denomination, are entirely different from one country to another. There is no point in explaining these differences to each other, and the discussion should concentrate on questions of principle.

The correspondence between the degrees in some countries may be summarized very roughly by the following little table, which is liable to correction.

	France	*W. Germany*	*Netherlands*	*Sweden*	*U.K.–U.S.A.*
1.	Licence		Candidaat	Fil. Kand.	Bachelor
2.	3e Cycle Astro	Diplom	Doctorandus	Fil. Licentiat	(Master)
3.	Doctorat	Dr. rer. Nat.	Doctor	Fil. Dr.	Ph.D.

The significance of the Master's degree is for the moment under discussion in the U.S.A.

1. *Astronomy in the Secondary Schools*

Full attention should be given to this stage of teaching:

(*a*) because it influences the recruitment of future astronomers;

(*b*) because astronomy has an incomparable intellectual value to any educated citizen.

The intellectual (moral, aesthetic) values of astronomy are clear to all of us. We should realize that the essentials of modern astronomy can be taught even on an elementary level and in a limited number of hours. There is hardly any other science which gives such an enlightenment of the mind within such a short time. The interest of the pupils for astronomy is spontaneous and

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very general, and schools should take advantage of this interest. Pupils should be brought to such a degree of knowledge that they will be able to understand popular articles in newspapers or general reviews.

From the answers to our questionnaire it becomes clear that the overall situation is still very unsatisfactory. In seven countries there is practically no teaching of astronomy in secondary schools. In many others, all depends on the personal interest of the teacher; or astronomy is an optional subject; or it is included in the course of 'General Science' and often forgotten. Only in the most favourable cases is there a systematic course, extending over 1, 2, or 3 year–hours.*

It may be expected that some of the elementary concepts, based on simple observations, have already been introduced at the primary school and in the lower classes of the secondary school. However, for a systematic course a more mature stage is to be preferred, corresponding also to more knowledge of mathematics and physics. One hour a week during the two closing years of the secondary school would seem a convenient minimum for such a course. If astronomy is combined with other topics into a course of General Science, it should have its obligatory place in this course and not be neglected.

The programme should be fundamentally changed to take into account the new developments of science.

In many countries, teaching is restricted to some elementary topics concerning the Earth, the Moon and the planetary system, including co-ordinate systems, little problems about the sphere and other tedious subjects—the whole being designated sometimes by the scholastic names of 'Cosmography' or 'mathematical geography'. These names should disappear and be replaced by the plain term 'Astronomy'.

We suggest that the programme be composed of two sections, their importance in time being about in the ratio 1 : 2.

(*a*) The structure of the Solar System; the Copernican revolution; some modern conceptions about the surface of the Moon, comets and meteors.

(*b*) The structure of the Universe: the Sun, the stars, the Galaxy, nebulae, extra-galactic systems.

It should be stressed that the second section is by no means more difficult than the first one. On the contrary! To teach the modern subjects will be found exciting: the interest of the pupils, and their intellectual reward, are most gratifying.

In most countries astronomy is taught either by the teacher of mathematics or by the teacher of physics. There is no doubt that (apart from the rare astronomer) by preference the physicist should be in charge of this teaching, on condition that he followed at least a course in general astronomy; such are the regulations in Czechoslovakia, Poland, Sweden. This should be contrasted with the case of Argentina and France, where only mathematicians are accepted. It is most deplorable that in some countries the great majority of those who teach astronomy have never themselves followed any course in the subject; special attention in that respect should be given to the teachers of General Science.

A modest telescope should be available at every secondary school, the objective having a size of say 7 cm. All care should be given to a stable mounting and to protection against the weather.

2. *The Training of the Future Astronomers at the University*

The scope of astronomy nowadays is so vast that nobody would be able to encompass the whole of it. Still less is this the case if we consider also the auxiliary sciences (mathematics, physics) which are indispensable for an astronomer. The first years of study should be devoted

*By 'a course of 1 year-hour' we mean that there is 1 hour a week during 1 year.

to a general orientation and to basic sciences, and specialization should begin during the second part of the study. Finally for his thesis the student should concentrate on one limited subject.

The main difference among the countries and the universities concerns that level at which the training of the astronomer branches off from that of the mathematician or physicist. In very few countries can the choice of an astronomical career be made from the start, and the future astronomer enjoys the optimum proportion between the three exact sciences. In many others, there is a common bachelor's degree (either with or without astronomy), after which the training concentrates more and more on astronomy. In others still, one has to acquire first a master's degree in mathematics or physics, and only then is the study of astronomy started. Even taking account of the great variation in university regulations, we should like to put forward some general wishes:

(*a*) If possible, some study of astronomy should be started in the first year. The student who chooses astronomy as a career cannot wait for years, studying mathematics and physics, before he is introduced to his science proper. A similar point of view is being more and more accepted in the university teaching of medicine and engineering. There is, otherwise, too great a danger that he deviates from his original purpose.

(*b*) Astronomy as a major topic should be started not later than after the bachelor's degree (after 3 years, say); otherwise it would be impossible to reach a sufficient knowledge of modern astronomical science.

(*c*) In some countries only some of the universities confer a degree in astronomy, and still fewer a Ph.D. Such a differentiation seems to afford a reasonable solution if the means are limited; it makes possible the raising of the standards. However, in any normally developed country there should be at least one university, where a Ph.D. can be acquired on an astronomical thesis.

As long as astronomy is hardly taught at the secondary schools, the position of this science at the university will be different from that of physics and mathematics, in so far that there has been no propaedeutic introduction. But even if the situation improves, a systematic course of General Astronomy remains essential. It is pointed out that there is lack of a modern, medium-level textbook.

No natural science should ever be taught without practical work. Students of astronomy should have regular exercises, not so much to teach them observing skill, but mainly to bring before their eyes the reality of the concepts introduced during the lectures. These practical exercises should be partly devoted to observations, partly to measuring and studying photographs, or to the practice of astronomical calculations. There should be student's equipment: photometers, comparators, micrometers, spectrographs.

Parallel to the general lectures it may be useful to have, also before graduation, one course on a more specialized topic, just to give the student an impression of the more scientific treatment of an astronomical subject. Examples: radiative transfer, stellar spectroscopy, binary stars.

After graduation a certain number of courses should be selected, according to the abilities of the staff, the predilection of the student, and the general direction of research at the institute. There is no difficulty in compiling a list of branches of astronomy on which such a course might be followed. However, too great a number of lectures would paralyse the student and deprive him of the possibility of developing his personal initiative, and of embarking upon research and invention. Much more important than encyclopedic knowledge is the interest for science, and the ability to acquire some familiarity with a new field, in which one has to work unexpectedly. If meritorious and celebrated astronomers were examined about their knowledge in the diverse fields of astronomy, physics and mathematics, the examiners would be surprised and horrified!

Regular colloquia are an excellent opportunity to present samples of fields of interest outside the normal courses. The students should also be encouraged to work regularly in the reading room.

The following examples of post-graduate courses are partly borrowed from the note of Prof. Bok; some are overlapping. Modern subjects such as radio astronomy and space research have been treated on an equal footing with the more traditional subjects.

Geophysics
Physics of planets and satellites
Comets
The interplanetary medium
Space research
Celestial mechanics
Gaseous nebulae
Interstellar medium
Galactic structure
Galactic dynamics
Double stars
Star clusters

The Sun
The Solar Corona
Solar and stellar atmospheres
Stellar interiors and evolution
Stellar spectroscopy
Variable stars
Extra-galactic systems
Radio-astronomical problems
Cosmic rays
Cosmology

Instrumentation: design problems (optical, electronic, mechanical); design of one piece of equipment; adjustment of telescopes and accessories.

Practical astronomy: photometric techniques (photographic, photoelectric); proper motions, parallaxes, radial velocities (measurement and reduction); advanced optics and electronics; radio-astronomical instrumentation and observation.

The U.S. conference expressed a wish that the student should become familiar with at least two observing techniques, while having some notion of the others.

There, it was also pointed out that some experience in teaching, be it only during a limited time, is most useful for graduated students, especially for the best ones.

It is a good procedure at first to let the graduate student work together with several staff members in succession, e.g. one month on each subject. This will give him an impression of the type of research in different fields. Then a special subject should be selected, the study of which is at the same time an exercise in exploring the literature and in original research. If this is successful, it may be a good start for a thesis.

Two other sciences are of old the fundamental aids to astronomy: mathematics and physics. In the course of the last half century the importance of physics for astronomy has tremendously increased, while the increase has been slower for mathematics and mechanics. A most important and eventful innovation, however, was the introduction of electronic computing machines, which enormously increased the possibilities of investigation in almost any field of astronomy. Moreover parts of mathematics have become important *because they are needed for mathematical physics*, indispensable for an astronomer.

In establishing a curriculum in these sciences with a view to the study of astronomy, we are confronted with a difficulty, already mentioned earlier: the scope of science increases quickly, whereas the duration of the studies should remain almost constant. The addition of new topics therefore has the consequence that others must be dropped, unless a quicker or more synthetic method of teaching such a field is found.

The importance given to mathematics and physics should never be increased to such a point that a serious study of astronomy proper becomes endangered. This danger has proved very real in some European countries. Moreover it would be easy to show, that high mathematical knowledge has rarely produced important discoveries in recent astronomy. (For physics this would not apply.)

A test was made on the basis of 83 papers, published in the *Astrophysical Journal* of 1962. For 60 per cent of these, no mathematics are involved beyond ordinary calculus and probabilities; 20 per cent require higher mathematics; 20 per cent require parts of theoretical physics, in which higher mathematics are involved.

Experience shows that students are often unable to make use of their mathematical knowledge when this has to be applied in a course of theoretical physics. It may, therefore, be considered whether some parts of mathematics should not be taught together with the branches of theoretical physics where they are particularly needed. In any case it would be desirable to make frequent applications to astronomical or physical problems during the courses of mathematics. This would considerably increase the interest of astronomy students.

The student of astronomy has to develop above all the ability to formulate an astronomical problem in terms of mathematical symbolism. If then the solution presents considerable difficulties, the aid of a mathematician should be asked.

In selecting the mathematical curriculum, good use can be made of the important report of the Mathematical Association of America (*Amer. J. Physics*, **30**, 569, 1962), containing a programme of courses, to be required of students majoring in physics or in engineering. From both lists we select a minimum, adding on the other hand a few topics, important for astronomers.

Beginning analysis–linear algebra–probability and statistics, correlation, least squares–functions of several variables–vector and tensor calculus–ordinary differential equations–functions of Bessel and Legendre–partial differential equations of mathematical physics–Fourier analysis and Fourier integral–notions of integral and integro-differential equations–machine calculus and programming.

How these subjects should be divided between the years before and after graduation should be determined partly by co-ordination with the courses in theoretical physics, partly by university regulations.

As has been stressed already, physics is nowadays the most important auxiliary science for the astronomer. In his first years he should study especially: mechanics, electromagnetism, optics, atomic and nuclear physics; and to a less degree: thermodynamics. There should be, of course, extensive laboratory work. After graduation, relativity theory, radio-physics, quantum physics, plasma physics, hydro-and aerodynamics, and electronics become important. However, it will be imperative to make a selection and to stick to those subjects most closely related to the future direction of one's astronomical research.

It should also be noted that in physics, just as in mathematics, the classical courses are not well adapted to the needs of the astronomer. They are too extensive on some topics, too brief on others. Two examples: in hydrodynamics turbulence is hardly mentioned, whereas it is of primary importance for an astronomer; quantum mechanics is rarely pursued to such a stage that the student is able to calculate a transition probability or a collision cross section.

During the work for the thesis or after its completion, a stay abroad for some time at one of the centres of astronomical activity is often of the greatest use. It is not at all necessary to choose one of the celebrated big observatories. In a specialized field a smaller institute may do equally good work, or better, and the foreign student may find more guidance in his work. The International Astronomical Union gives grants to cover travel expenses.

An astronomer's study does not finish when he has acquired the doctor's degree. For his research and teaching he will have to keep up with the progress in his field of specialization, and more superficially with the big advances in other fields. When an entirely new subject becomes important, he should have the opportunity to follow special courses on such topics. The importance of such post-academic training is more and more recognized in all sciences. The courses organized at Varenna are excellent examples of such training.

3. *Astronomy as a Minor Topic for Mathematicians and Physicists*

At the moment of his entrance into the university the student in general knows very little about astronomy, higher mathematics and physics. It is, therefore, a good arrangement if the study of these sciences is not too specialized from the start, so that the possibility is left open to switch over if his predilection changes.

Some knowledge of astronomy for the future mathematician or physicist had indubitably a high educational value. For both of them it will be of great interest to see how their sciences are applied to a natural science, which more than any other has reached quantitative precision. Astronomy has always been a source of inspiration for the physicist, because it gives him the opportunity to study matter under circumstances vastly exceeding the possibilities of the laboratory. Moreover, the technical demands of astronomy have stimulated him to find new solutions in instrument design.

A course of general astronomy is therefore of great use to mathematicians and physicists, be it only as a minor subject of their programme before graduation. Later, some of these students may be seriously interested and may wish to study in a more thorough way some special branch of astronomy or they may become attracted by a career in astronomy.

In 17 out of 29 countries, a course of astronomy belongs to the normal curriculum of all undergraduate students in mathematics or physics. In six countries such a course is optional. It should in any case be compulsory for future teachers of physics.

It seems important, in many respects, that contact be kept between astronomers and physicists after graduation. Some astronomical courses should be optional for physicists. Frequent relations should especially be kept with spectroscopic and electronic laboratories.

Very effective are the summer courses, organized by the Royal Greenwich Observatory, by the Mt Stromlo Observatory, by the U.S. National Radio Observatory, and by the Kitt Peak Observatory. Some good students, who have graduated in mathematics and physics, get the opportunity to take part in research and to serve as night-assistants. It turns out that often a few of them are definitively attracted towards an astronomical career.

4. *Astronomy for Students of all Faculties*

In countries such as the U.S.A., the college students have a broad possibility of choice for their courses. Elementary general astronomy is presented in such a way, that it can be understood by almost any student; many avail themselves of this possibility. Altogether 8 out of 29 countries have similar courses, partly belonging to a 'Studium Generale', which all students are free to follow.

5. *Recruitment of Professional Astronomers*

In 20 out of the 29 countries there is a shortage of astronomers. From the U.S.A. we are informed that the increased demand refers mostly to rather narrowly educated specialists and technicians, for which the truly astronomical part of the training is not essential.

Several countries emphasize that the number of students attracted towards our science is mainly determined by the prospects of a successful career. The salaries; the future positions; the number of potential competitors; the amount of routine work, detracting from research proper; the stability of the position; they all play a role, especially because the competition with physics is considerable. This is the reason why in such countries there is a shortage of astronomers for routine work, which is in little esteem and offers few possibilities of promotion. Some new countries complain about the insufficient payment of scientists.

In other countries more weight is given to the specific vocation for astronomy, which has always been a strong tradition. It seems that in the modern world this tradition has lost some of its power. In any case astronomers should take care that the material recognition of their work be comparable to that of physicists and mathematicians. Then only the students will be really 'free' to follow their predilection.

Another important point is, that the freshmen should be sufficiently aware of the attractions of an astronomical career. The American Astronomical Society has a pamphlet on this subject, which is widely distributed among high-school teachers. The astronomy courses for undergraduate students in mathematics and physics, the summer courses mentioned under section 3, serve a similar purpose.

Report of Meetings, 29 August 1964

PRESIDENT: M. G. J. Minnaert.

SECRETARY: L. Perek.

Prof. M. G. J. Minnaert presented his report on the Teaching of Astronomy and asked for comments.

Prof. W. Iwanowska advocated the teaching of some rudiments of spherical astronomy as a basis for further training. Teaching in secondary schools being a vast field of employment for astronomers, courses on the methods of teaching science and a practical training in teaching should be given to students. The teaching programme should be balanced as regards the amount of time accorded to mathematics, physics, and astronomy. At the level of a graduate student some sort of teaching is the most efficient way of learning. As an example of a programme for students in astronomy, she showed the programme adopted in Poland, including the courses, exercises, seminars, examinations, and mentioning the numbers of hours devoted to each of these activities. This interesting programme includes also a training of one month at another observatory.

Prof. B. J. Bok then expressed his views as follows:

GENERAL COMMENTS

Bart J. Bok

My brief remarks are intended to be comments on specific points in Prof. Minnaert's report. Before I present these, I should express my admiration for the skill shown by Prof. Minnaert.

First, he assembled the basic material on the teaching of astronomy in many parts of the world, and, second, he analysed all of this material and presented it to us today in such a beautifully coherent form.

The report skips too quickly from the problems of the teaching of astronomy in primary and secondary schools to the place of astronomy in the first years at the universities. I am firmly of the opinion that astronomers themselves have responsibilities to attract promising young students into the profession and we should make special efforts to show them the fine opportunities that lie ahead. There are many ways in which we can help get the most promising 15–17 years old boys and girls—to obtain a clear picture of the attractions of a career in astronomy. The making available of special career pamphlets is one way. The giving of public lectures and especially of school lectures by active research astronomers is another way which can often help overcome the initial hesitation that most young people have in entering upon study for a somewhat unusual profession. A visit to an active observatory and direct contact with research astronomers can often be decisive for a good prospect and encouragement given at a Science Fair or at a Science Talent Search can also help significantly. Astronomers must not hesitate to get out into the market-place and recruit!

I agree most heartily with Minnaert's proposition that a student in the university cannot wait—and will not wait—for years to be introduced to astronomy. While it is true that at the start much of the emphasis must be on the study of mathematics and physics, there must be a good basic course in astronomy at an early stage. And the student should be given the opportunity to visit observatories regularly and get a feeling early in his training for the research and routine work being done. I shall describe towards the end of this talk how we can and should make full use of the summer periods in furthering this aim.

At all stages in the teaching of astronomy, we should keep the student aware of the beauty and grandeur of the universe that we are privileged to study. The teaching of astronomy at all levels should include regular observing periods. The beginning student should learn his constellations, know the planets and learn to follow their paths across the heavens and observe the Milky Way and its beautiful clusters and nebulae. At a more advanced stage, work at the telescope—optical or radio—should be a part of his training course. Work at night should be firmly related to practical work in the laboratory, to measurement and to analysis.

I am very much in favour of our providing opportunities for overseas experience for our recent Ph.D's. Right after the award of the Ph.D. degree, the young astronomer should be encouraged to work at a research observatory outside his own country, for otherwise he may come to think that he knows all the answers. Most young Ph.D's learn during the first year after the award of the degree that astronomers at other institutions and in countries outside their own can have approaches to research in the field very different from the approach during his years of Ph.D. study at the home university.

Travel overseas is expensive and must be defrayed on some international basis – especially so since our young Ph.D's will want to take their wives (or husbands), and often one or two young children, with them on their first Ph.D. travels overseas.

The Minnaert Report summarizes nicely outlines for the course work during the Ph.D. training. After the basic training in physics, mathematics and astronomy is finished (the first three or four years at the university), the student should have at least one year of good tough courses or seminars in astronomy. These should each culminate in an oral or written examination (with my preference definitely for the oral examination), for this is the time to weed out the poor prospects. I favour for the second year of graduate study a somewhat more lenient approach, with the emphasis on absorbing additional material rather than on examinations. And by the time the third year comes around, no good student will want to attend many more lectures and all we can do is to train him further through attendance at colloquia and the work on the doctoral thesis.

I believe most strongly that in the training of our future Ph.D.'s there is no such thing as a single road to salvation. Diversity of approach is essential already within one country—and it would be silly to think in terms of uniformity on an international scale. But central to all programmes of training is that there must be continuing intimate contact between the student, his teachers and his research director. Astronomers are best formed by a process that has many of the characteristics of osmosis.

There is one way in which astronomy teachers in all parts of the world can pool their experience—and that is by the exchange of lecture notes in mimeographed (or, if you prefer, duplicated) form. Here is a place where a Commission on the Teaching of Astronomy in the

IAU might undertake some useful work. Facilities for mimeography might be provided, or small financial assistance might be given to help in the reproduction of course material. Furthermore, our new Commission might well serve as a clearing house for information regarding availability of mimeographed courses of an advanced nature. It is far easier to produce a good set of course notes than it is to write a textbook.

Next, I wish to stress the importance of our making full use of the summer periods to further the training of future astronomers. I have for three decades been a strong believer in the efficiency of summer schools and summer institutes at all levels. These can be of many varieties and I shall list a few samples.

1. Young physics (or mathematics) students should be given the opportunity to come as summer vacation students (or scholars) to the larger observatories in their country. They should not only be lectured to, but they should learn through service in training how a research astronomer works.

2. Advanced Ph.D. students and recent Ph.D.'s (as well as some not-so-recent-ones!) should be given the opportunity to attend special advanced summer courses and institutes. I have been very much impressed by the potentialities of the summer programmes offered by the U.S. National Science Foundation and courses like those at Varenna and summer courses organized under NATO's Science Programme. The Course Notes for these lectures should be distributed promptly and widely—preferably within a few months after the end of such a course.

3. I see a real need for summer courses aimed specifically at technicians and engineers primarily engaged in the design and building of astronomical equipment. Here the need is not only on a national, but also on an international basis. Much of the success of our present-day research work depends on the assistance that we as research astronomers receive from our electronic, mechanical and optical engineers and technicians. We should give them the opportunity to learn and get to know each other at special institutes and courses—most of them of an international character. UNESCO might well take a hand!

In the part of the world from where I come, Australia, we feel strongly the need for more activities on a regional basis. We are surrounded by emerging nations—Indonesia, Thailand and the Philippines, to name a few. There is scope for increased regional activities in the training of future and existing astronomers. Here again I wish to stress the importance of in-service training. For the somewhat older participants in programmes of this sort, I would advise such training without the promise of a degree at the end of the year. At Stromlo we have had happy experiences with visitors from Indonesia and from Pakistan who spent a year of work at our observatory, who listened to courses without necessarily taking examinations and who entered fully upon the life of the observatory.

Prof. V. Kourganoff then expressed the following point of view on the international co-operation in the teaching of astronomy:

SUR LA COOPÉRATION INTERNATIONALE DANS L'ENSEIGNEMENT DE L'ASTRONOMIE

V. Kourganoff

Les astronomes ont toujours été à l'avant-garde d'une coopération internationale active, comme le prouve l'existence même et la vitalité de l'UAI.

Cependant cette coopération s'est exercée jusqu'ici principalement dans le domaine de la Recherche.

L'excellent rapport préliminaire du Prof. Minnaert rappelle opportunément l'urgence et l'intérêt d'une extension de cette coopération à l'enseignement de l'astronomie, à tous les niveaux, depuis l'Enseignement Secondaire jusqu'à la formation des astronomes.

Certes l'UAI intervient déjà activement dans cette formation par les allocations distribuées sous le contrôle de la Commission de l'échange des astronomes (Commission 38), en facilitant la participation aux recherches hors des frontières nationales.

Il est cependant évident que la formation par un apprentissage de la recherche, bien qu'absolument indispensable, n'est pas suffisante, et doit être équilibrée par un enseignement convenablement organisé et structuré, si l'on veut éviter une spécialisation trop étroite et assurer une 'culture astronomique' suffisamment générale, en plus de la culture scientifique donnée par la préparation de la Licence physico-mathématique.

Comme le souligne à juste titre le Prof. Minnaert, les Licences sont mal adaptées aux besoins des astronomes, aussi bien futurs chercheurs que futurs professeurs de Lycée, tant par l'importance relative accordée aux mathématiques et à la physique, que par le sacrifice des fondements de l'astronomie au profit des matières jugées, à tort, d'un intérêt plus général.

Aussi, bien que nous soyons tous plus ou moins visés par ses critiques, nous accorderons au Prof. Minnaert qu'il n'existe même pas, à l'heure actuelle, de bon traité moderne d'Astronomie Générale, au sens large, au niveau de la Licence.

Ainsi ce n'est pas au cours de leur Licence ('undergraduate studies') ni en dépouillant des spectres ou des enregistrements photométriques, que les étudiants apprendront 'à formuler les problèmes astronomiques sous une forme mathématique', pour reprendre, une fois de plus, une excellent formule du Prof. Minnaert, ni à enseigner correctement l'astronomie au niveau du Lycée.

Conscients de cette double insuffisance : celle de la simple participation aux recherches et celle des programmes de la Licence vis-à-vis de l'Astronomie, de nombreux astronomes se sont efforcés, avec plus ou moins de succès, d'introduire davantage l'Astronomie au niveau de le Licence, et surtout d'offrir des enseignements 'organisés' d'astronomie s'adressant à des étudiants déjà licenciés ('graduate students').

Hélas, tous ceux qui se consacrent à cette tâche, exaltante mais ingrate, connaissent bien les graves obstacles qui limitent les élans de leur zèle pédagogique. Le principal de ces obstacles provient incontestablement, dans tous les pays moins vastes que l'U.R.S.S. ou les U.S.A., de la faiblesse numérique d'étudiants susceptibles de s'intéresser (ou s'intéressant effectivement) au sein de chaque Faculté nationale, ou même au sein d'une nation donnée tout entière, à l'Astronomie.

'Vi er saa faa her i landet . . .' (we are so few in this country . . .), ce cri poussé à une autre occasion par le grand poète norvégien Nordald Grieg, chaque astronome pourrait le prendre à son compte!

Cette difficulté de 'recrutement en élèves' est considérablement aggravée dans la plupart des pays, d'une part par les tâches écrasantes confiées aux jeunes licenciés qui enseignent dans les Lycées, et, d'autre part, (ayons le courage de le constater), par l'étroitesse de vues de nombreux 'directeurs de recherches', plus sensibles à la 'poésie du Ciel' qu'aux grandes théories physiques, et qui n'encouragent pas toujours suffisamment la fréquentation d'enseignements organisés pour leurs jeunes disciples.

Aussi, même si nous sommes tout prêts à accorder au Prof. Minnaert qu'un trop grand nombre de tels cours 'pourrait paralyser l'étudiant et le priver de la joie de développer son initiative personnelle', nous ne pouvons souscrire sans réserves à un texte qui suggère qu'une étroite spécialisation et un manque de culture générale sont normaux chez des astronomes de 'mérite reconnu'.

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On peut, au contraire, se demander, si une relative stagnation de l'astronomie, au cours de ces 20 ou 30 dernières années, en ce qui concerne le renouvellement de nos conceptions de l'astrophysique, après le développement explosif du début du XXème siècle, n'est pas due, précisément, à la disparition progressive d'astronomes, de 'grands astronomes', ayant la culture générale d'un H. N. Russell ou d'un Eddington.

Quoi qu'il en soit, il est incontestable qu'un minimum d'enseignement organisé (qui ne doit pas prendre nécessairement la forme d'un cours ex cathedra) est indispensable, et non moins incontestable qu'il y a généralement une navrante disproportion entre la qualité des enseignements de l'astronomie 'extérieurs' à la licence, et le nombre d'étudiants qui profitent de tels enseignements, dans les pays de moyenne et de faible 'population universitaire'.

On est ainsi conduit à rechercher la solution du problème dans une internationalisation progressive de l'enseignement de l'astronomie, ou, tout au moins, dans un effort accru pour developper les différentes formes de coopération internationale dans le domaine de l'enseignement, ce qui, après tout, s'inscrit directement dans le cadre de l'inévitable planétarisation de toutes les activités humaines!

Certes, la réalisation pratique de cette entreprise ne manquera pas de soulever de considérables difficultés, financières, linguistiques et politiques. Et certains collègues, connus pour leur esprit critique et leur scepticisme systématique, se feront un plaisir de démolir, en quelques phrases brillantes, notre proposition. Un tel jeu de massacre est toujours facile et amusant, car tout projet est à sa naissance aussi vulnérable qu'un enfant qui vient de naître, pour reprendre le mot célèbre de Faraday.

Mais nous sommes sûrs aussi, qu'il existe parmi les astronomes des 'idéalistes réalisateurs' qui, sensibles à la signification d'une telle entreprise pour le rapprochement entre les peuples et les progrès de l'astronomie, sauront trouver la méthode la plus efficace pour passer, avec certains détours inévitables, du plan théorique au plan pratique. L'exemple du COSPAR montre comment quelques hommes énergiques de bonne volonté arrivent à vaincre des tendances nationalistes même dans un domaine aussi délicat que celui des recherches spatiales.

Essayons de résumer, à leur intention, l'essentiel des remarques précédentes, et de préciser quelques modalités pratiques.

Il s'agit de voir comment la mise en commun, à l'échelle internationale, tant d'étudiants que des professeurs, pourrait permettre l'éclosion de 'cours' au sens large qui auraient pu se faire et ne se font pas encore faute de 'marchés nationaux' assez vastes pour de telles 'marchandises'.

Quand on considère le nombre d'ouvrages astronomiques publiés en anglais ou en russe on a l'illusion que le problème est déjà entièrement résolu. En fait, il n'en est rien, car les ouvrages en russe sont inaccessibles à la plupart des astronomes 'occidentaux', tandis que, faute d'une connaissance suffisante du français ou de l'allemand, la plupart des anglo-saxons n'ont presque aucune connaissance des ouvrages publiés en France ou en Allemagne.

En outre, le nombre d'ouvrages de cette dernière sorte pourrait être beaucoup plus considérable si la création d'ouvrages 'standard' de différents niveaux, par des auteurs de langue française et allemande, et à plus forte raison d'autres langues (en dehors de l'anglais), n'était terriblement limitée par des critères de rentabilité commerciale (et parfois un certain chauvinisme linguistique interdisant à l'auteur d'utiliser une autre langue que sa langue nationale)! On retrouve ici le handicap de la faiblesse numérique du 'sous-système' des astronomes dans la Galaxie universitaire.

Voici, en conséquence, un 'calendrier provisoire' que l'on pourrait envisager sur le plan des réalisations pratiques, en commençant par les mesures les plus urgentes et les plus faciles:

1. Constitution d'une 'Commission pédagogique' dont une 'sous-commission' *sélectionnerait* les ouvrages d'astronomie, de différents niveaux, allant de la vulgarisation au niveau le plus

élevé, écrits en une langue autre que l'anglais et qui effectuerait des démarches appropriées auprès des éditeurs anglo-saxons pour leur recommander la publication d'une traduction anglaise de ces ouvrages, en stimulant éventuellement leur intérêt, par une subvention de l'UAI ou de l'UNESCO, proportionnelle au 'déficit' probable d'une telle publication.

2. Cela nous conduit à inviter les principaux responsables de l'UAI à rechercher, en s'appuyant peut-être sur l'UNESCO, des *moyens financiers* propres à favoriser d'une manière générale le travail de traduction et l'impression de livres, soit par des subventions dont il été question plus haut, soit, de préférence, entièrement aux presses propres de l'UAI.

Le travail de traduction pourrait être rétribué sous la forme de bourses accordées à de jeunes astronomes connaissant plusieurs langues.

3. Une fois résolu ce problème fondamental de financement, la 'commission pédagogique' pourrait charger un petit groupe d'astronomes, connus pour leur talent d'exposition, de la *rédaction* d'un certain nombre d'ouvrages 'standard' (sur les différents sujets mentionnés par le rapport du Prof. Minnaert), en prévoyant 2 ou 3 ouvrages de conception 'complémentaire' sur chaque sujet important pour tenir compte de différents points de vue possibles entre auteurs d'égale compétence.

Tous ces ouvrages 'standard' seraient soit écrits directement en anglais, soit traduits en anglais avant publication, dans le cadre des solutions déjà trouvées pour la publication des traductions dont il a été question plus haut.

[N.B. On pourrait s'étonner du privilège que nous semblons accorder à la langue anglaise, et cette conception pourrait heurter certains 'nationalismes linguistiques'. Mais nous partons simplement d'un état de fait, à savoir, qu'actuellement l'anglais est la seule langue lue courramment par tous les astronomes. Si dans quelques années cette langue 'universelle' était remplacée par le français ou le chinois, je ne verrais aucun inconvenient à ce que toutes les publications astronomiques soient traduites exclusivement en cette langue-là!]

4. Une quatrième étape consisterait dans la publication de *livres d'exercices*, afin de donner à l'étudiant un 'working knowledge' des généralités de l'astronomie.

L'excellente suggestion de Mr I. Atanasijević, visant à transformer en exercices méthodiques certains mémoires originaux, pourrait se réaliser ainsi dans un cadre international.

5. Parallèlement au développement d'une 'littérature' consacrée aux exercises théoriques, il faudrait élargir la conception des cours d'été. Ne plus se borner à des séminaires 'semi-spécialisés' du type Varenna, mais choisir un lieu permanent, d'accès facile, situé dans un cadre agréable, comme l'Observatoire de Nice par exemple, pour y organiser des *travaux pratiques* d'un niveau élevé et des exercices 'avancés', ainsi que des enseignements plus élémentaires pour la formation et le recyclage des professeurs d'astronomie dans les Lycées.

6. Pour finir, on pourrait essayer d'organiser un *Centre International pour l'Enseignement de l'Astronomie*, fonctionnant en permanence pendant toute l'année, soit par correspondance, soit à coup de 'visiting professors', avec des étudiants qui y passeraient entre 6 et 12 mois, sans examen final (pour éviter le bachotage), mais avec un diplôme fonction de l'ensemble de leur activité de l'année, pour satisfaire à la tendance de plus en plus forte parmi les étudiants de penser plus à leur promotion sociale qu'à la satisfaction de leur curiosité.

Un tel Centre serait très utile pour assurer un 'brassage' des jeunes de toutes nations, et avancerait beaucoup la 'planétarisation' des esprits.

Prof. D. Layzer stressed the essential features of physical sciences: (*a*) the use of mathematics as a language and (*b*) the fact of dealing with the external world in a rigorous and quantitative way, both on an observational-experimental level and on the theoretical level. Survey courses give to beginning students a very inadequate idea of (*b*). The problems of space, time, motion, light, gravitation, and structure of the universe, can be taught in depth to first- and second-year students.

'Here is,' said Professor Layzer, 'an important opportunity for astronomers to promote the unity of the physical sciences and to introduce astronomy at an early stage to a much wider group of beginning scientists than we reach, in the U.S., at the present time.'

At the graduate level, it is important to maintain the highest scholastic standards in the selection of the students.

In the discussion on special subjects, *Prof. I. Atanasijević* explained as follows his method of astrophysical exercises:

TRAVAUX PRATIQUES D'ASTRONOMIE EN LABORATOIRE

I. Atanasijević

L'organisation des travaux pratiques d'astronomie en général est, en soi, un problème assez vaste et trop complexe pour qu'il puisse être traité à fond dans le cadre d'une brève communication. Je serai donc obligé de me borner à certains de ses aspects.

Tout d'abord quelques considérations générales.

Les travaux pratiques font partie intégrale d'un cours. Leur caractère sera donc déterminé par celui du cours professé. En ce qui concerne cet aspect de la question, le cas suivant me semble assez typique: l'astronomie est enseignée, tout d'abord, dans le cadre d'un cours élémentaire qui s'adresse à un auditoire assez large, où parmi des étudiants d'astronomie figurent aussi des étudiants en physique et mathématique. C'est ce qu'on appelle un cours d'astronomie générale (cours de Ier cycle). Ensuite, dans le cadre du IIème cycle, des cours plus spécialisés, d'un niveau nettement plus élevé, seront professés aux étudiants ayant déjà acquis des connaissances générales d'astronomie, de physique et des mathématiques. Ces cours de IIème cycle grouperont d'un côté l'astronomie classique et, de l'autre, l'astrophysique dans le sens large du mot. Ils seront encore d'un caractère assez général, ce qui ne nous empêche point de mettre l'accent sur tel ou tel chapitre. De ce fait même nous serons en mesure d'approfondir certaines questions et de préparer la voie aux cours spécialisés de IIIème cycle.

Le temps ne me permet pas de discuter à la fois les travaux pratiques d'astronomie générale et ceux qui font partie des cours de IIème cycle. Or ce sont ces derniers qui me paraissent beaucoup plus intéressants et importants. Je me propose donc de faire quelques remarques à leur sujet.

En principe les travaux pratiques de IIème cycle peuvent être conçus en partant de deux points de vue assez différents, voire opposés.

D'un côté, on pourra se concentrer sur une méthode ou une technique bien déterminée et la développer avec beaucoup de détails. Certains principes très généraux étant à la base de plusieurs méthodes, la connaissance de l'une d'entre elles devrait, au fond, permettre de se familiariser assez facilement avec les autres. Cela serait valable même si elles n'ont pas fait l'objet de l'enseignement.

D'autre part, on pourra se fixer le but de démontrer aux étudiants les principes de méthodes

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et techniques, de leur donner l'occasion de retrouver eux-mêmes, par leur propre expérience, les principaux faits qu'on leur a exposés dans le cours professé.

Dans le premier cas, et comme il s'agit des étudiants, on risque, je le crains, de substituer à un enseignement dans le sens propre du mot, un apprentissage. Vu la complexité des méthodes et techniques, l'étudiant risque de ne pas voir la forêt à cause des arbres. Enfin il me semble que, pour pouvoir vraiment entrevoir ces principes généraux auxquels j'ai fait allusion, il faut une maturité d'esprit à laquelle on ne peut pas s'attendre chez des étudiants. Les avantages de cette méthode d'enseignement pourraient bien n'être qu'apparents.

Si l'on adopte le deuxième point de vue, on aura à developper des travaux pratiques d'un caractère bien varié, mais, en même temps, assez général. Ceci pourrait être considéré comme un inconvénient. Cependant, dans le cadre d'un enseignement de IIème cycle qui nous intéresse ici, l'étudiant aura l'occasion d'approfondir ses connaissances sur tel ou tel sujet par un travail individuel mais obligatoire (travail de diplôme, travail de séminaire). De plus, il est à remarquer qu'une véritable spécialisation ne saurait avoir lieu qu'en IIIème cycle. Enfin, et surtout, il me semble que l'enseignement de IIème cycle représente la dernière occasion (sinon la seule) de fournir aux futurs astronomes des connaissances à la fois assez larges et solides. Les inconvénients de cette seconde méthode ne seraient, donc, pas trop graves.

Pour ces raisons je suis plutôt enclin à adopter le second point de vue.

Regardons maintenant de plus près en quoi consisteront, dans ce cas, les travaux pratiques. En principe ces travaux comprendront:

(*a*) l'étude, au laboratoire, de certains phénomènes physiques ayant un interêt particulier;
(*b*) l'étude des appareils et des dispositifs;
(*c*) des observations;
(*d*) le dépouillement de résultats d'observations;
(*e*) la détermination de certaines grandeurs fondamentales et la vérification de certaines théories.

Je reviendrai plus tard sur ce point qui me paraît particulièrement important.

En bref, et comme le Prof. Minnaert l'a très justement souligné dans son rapport, le but des travaux pratiques sera moins d'apprendre aux étudiants l'adresse des observations (ou la technique de calculs), que de leur montrer la réalité concrète des concepts traités dans les cours.

Après ces considérations générales, permettez-moi de vous présenter, à titre d'exemple, les travaux pratiques que j'ai pu réaliser, ces dernières années, à la Faculté des Sciences de Belgrade, avec l'aide active de mon assistante Mlle Milogradov.

Le cours d'astrophysique dont ils font partie a dû se borner, pour des raisons spéciales, à l'exposition des méthodes et techniques d'observations, des résultats d'observations, des éléments d'astronomie stellaire. Ce cours, d'une conception un peu classique, sera complété, dès cette année scolaire, par des éléments d'astrophysique théorique et de physique solaire, de façon à mieux équilibrer toutes ses parties. Je signale enfin que c'est le premier cours d'astrophysique qui ait été enseigné chez nous.

Comme il ne saurait être question d'entrer dans les détails, je dois me contenter de vous citer des exemples typiques de chaque classe de travaux pratiques.

(*a*) Étude de certains phénomènes physiques:
aberrations des systèmes optiques, diffraction, absorption de la lumière par les filtres colorés et interférentiels.

(*b*) Étude d'appareils et dispositifs:
réfracteur équatorial muni d'une chambre photographique (astrographe), distances focales d'objectifs et oculaires, photomètres visuels, cellule photoélectrique avec

amplificateur à courant continu, prisme-objectif, propriétés directives des antennes, radio-interféromètre méridien (de type Ryle) pour ondes décimétriques.

(*c*) Observations: sujet qui intéresse surtout les étudiants. On indique un objet déterminé (l'étudiant ayant le droit de proposer en plus des objets de son choix) dont il faut prendre un cliché. A l'aide des atlas célestes de Bečvař l'étudiant aura à choisir une étoile de repère, prendre le cliché, le développer. Enfin il procèdera à l'identification de l'objet, au besoin à l'aide du Lick Observatory Sky Atlas. Prise des spectres à l'aide du prisme-objectif, enregistrement du passage du Soleil (source quasi-ponctuelle) à l'aide du radio-interféromètre.

Ces manipulations font partie du cours consacré aux méthodes et techniques. Par suite du manque de matériel, ainsi que pour d'autres raisons, certaines d'entre elles ont été d'un caractère qualitatif. Cependant, dès cette année scolaire, nous pourrons les remplacer par des mesures. En radioastronomie, par exemple, nos étudiants auront la possibilité de déterminer les caractéristiques (fréquence nominale, largeur de bande, facteur de bruit) d'un récepteur pour ondes décimétriques, d'étudier l'adaptation d'une antenne (à l'aide d'une ligne de mesures), de mesurer les pertes dans un cable coaxial.

La deuxième partie des travaux pratiques, celle qui correspond à l'exposition des résultats de recherches comprend:

(*d*) dépouillement des résultats d'observation—deux exercices.

Etant donné les magnitudes apparentes d'une variable (périodique) on procède à la détermination des éléments de sa variation d'éclat (époque initiale, période, amplitude). On a à construire la courbe de lumière, dont on tirera des valeurs approchées des éléments. Ces valeurs seront corrigées par la suite (application des moindres carrés); on procédera à la construction d'une courbe moyenne et des points normaux. Cet exemple a été tiré d'un excellent petit manuel écrit par le regretté Prof. Parenago et le Prof. Kukarkin (en russe).

En partant des vitesses radiales d'un double spectroscopique, on détermine, par la méthode de Lehmann-Filhes, les éléments provisoires de son orbite. L'intégration de la courbe de vitesse est faite à l'aide d'un planimètre. Les vitesses radiales seront prises dans un article publié.

Nous espérons pouvoir compléter ces exercices par la détermination des éléments de l'orbite d'une variable à éclipses.

Permettez-moi de vous présenter avec un peu plus de détails les exercices mentionnés sous:

(*e*) à savoir: la détermination de certaines grandeurs fondamentales ainsi que la vérification de certaines théories. Là nous nous sommes laissés guider par l'idée suivante, qui nous a paru séduisante:

L'exposition des résultats de recherches, bien qu'illustrée par des données numériques, des diagrammes et des développements mathématiques, et fort importante en soi, risque de paraître, aux étudiants, trop verbale, ennuyeuse, les théories peut-être même spéculatives. Ne pourrait-on, donc, procéder de façon à ce que l'étudiant retrouve lui-même les résultats cités, du moins les principaux?

Dans cet ordre d'idées nous avons réalisé jusqu'à présent les exercices suivants:

1. Détermination de la position de l'équateur galactique en partant de la distribution des amas galactiques ou des étoiles O. On adopte une simple méthode graphique. Données: catalogue Bečvař, liste des étoiles O et WR de Mme C. H. Payne Gaposhkin. Résultat: 1950·0 (pôle), $\alpha = 12^h\ 48^m$, $\delta = +\ 28°$.

2. Détermination des coordonnées sphériques du centre galactique basée sur l'étude de la

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distribution des amas globulaires, ainsi que des variables Mira Ceti (périodes de 150 à 200 jours) Données: Liste des amas de Mme H. Sawyer Hogg dans *Encyclopaedia of Physics*, Catalogue général d'étoiles variables (édition 1958). Résultat: $l_0 = 328°$, $b_0 = +2°$.

3. Etude du mouvement des Hyades. Données: mouvements propres pris dans l'article de van Bueren (*Bull. astr. Inst. Netherlds.*, 1952), vitesses radiales tirées du Catalogue Wilson (1953). On choisira selon certains critères dix étoiles et l'on déterminera les coordonnées du point convergent. La méthode de Charlier a été développée dans le cours. On trouvera ensuite les vitesses spatiales des étoiles choisies et leurs distances. Résultats:

$$\alpha = 96°,\ \delta = +7°{\cdot}5,\ \text{i.e.}\ \alpha = 6^h\,24^m,\ \delta = +7°{\cdot}5,\ V = 42\ \text{km/s},\ d = 40{\cdot}6\ \text{pc}.$$

4. Effets différentiels de la rotation galactique sur les vitesses radiales des Céphéides. Données: pour les vitesses radiales—article de D. N. Stibbs (*M.N.RAS*, 1956)—on aura à les corriger de l'effet du mouvement du Soleil vers l'apex. Magnitudes apparentes moyennes: Catalogue général d'étoiles variables (édition de 1958). Courbe période—luminosité et coefficient moyen d'absorption: Allen, *Astrophysical Quantities*, Ière édition. Toutes les formules nécessaires sont développées dans le cours. On a choisi 24 étoiles bien réparties en longitude galactique, et dont les distances déterminées photomètriquement (travail à faire par l'étudiant) sont comprises entre 1·0 et 1·5 kpc. On fera d'abord une représentation graphique du rapport de la vitesse radiale à la distance au Soleil, cela en fonction de la longitude galactique. On retrouve bien l'effet prévu par la théorie. On en tire le sens de la rotation et retrouve la valeur de la longitude du centre galactique. Ensuite on détermine la constante A de Oort (application des moindres carrés).

Résultat: $A = 20\ \text{km/s}^{-1}\ \text{kpc}^{-1}$.

5. Etude de la distribution de l'hydrogène neutre dans le plan galactique. Données: profils de la raie 21 cm de l'hydrogène neutre, article de Muller, Oort et van de Hulst (*Bull. astr. Inst. Netherlds*, 1954). Distance du Soleil au centre galactique et vitesse angulaire de la rotation: *Information Bulletin IAU* no. 11. 1963: recommandation du groupe de travail.

La formule à appliquer a été démontrée dans le cours. Il s'agit ici d'une répétition partielle du travail classique de Muller, Oort et van de Hulst. L'étudiant aura à déterminer les positions des zones d'hydrogène dont le rayonnement a été mesuré. En les portant sur un graphique il se rendra compte de sa distribution spiralée. Le travail est à faire pour dix directions dans le plan galactique, pour des distances supérieures à la distance du Soleil au centre galactique, en se servant des profils faciles à interpréter. On retrouve bien les trois bras spiraux (article cité, figure 11).

Nous comptons par la suite développer ces travaux pratiques surtout en les complétant par des exemples tirés de la théorie des atmosphères stellaires.

Un manuscrit couvrant toutes ces exercices a été préparé (en yougoslave).

Enfin, et à titre de conclusion, quelques remarques.

Dans le cadre de cette deuxième partie de travaux pratiques, nos étudiants ont dû se livrer à de longs calculs, feuilleter des tables de fonctions et des catalogues, préparer et utiliser des graphiques. Même quand il s'agissait des étudiants dont le succès général laissait à désirer, ils ont fait le travail d'une façon bien propre, ce qui est signe de l'intérêt qu'ils ont pris à le faire.

Evidemment, on ne devrait pas se faire l'idée fausse que la méthode adoptée soit la meilleure, ni que ses réalisations dont je vous ai parlé ne pourraient être perfectionnées. Il nous semble, quand même, que ce programme permet, dans son ensemble, de démontrer les aspects principaux et variés de la recherche. Nous croyons qu'il est très important et utile que l'étudiant retrouve lui-même les faits principaux, qu'il puisse refaire, dans la mesure du possible, quelques travaux classiques, qu'il prenne connaissance des catalogues, manuels et articles originaux et qu'il apprenne à s'en servir. Enfin et surtout, il pourra se rendre compte des liaisons multiples et complexes qui existent entre les phénomènes et concepts qui ont été enseignés. C'est en cela que résiderait, à notre avis, l'intérêt principal de la méthode que nous avons adoptée.

Prof. W. Liller, speaking also in the name of *Prof. C. D. Shane*, reported on educational motion pictures in astronomy. High quality motion pictures at the level of the secondary schools will be made widely available. The chief performer describes his own research.

Prof. M. Golay stressed that astronomy nowadays is not only needed for research workers, but also for many specialists and technicians in industry, telecommunications, space-research. The IAU should make a survey of the nature of astronomical knowledge necessary for these different types of specialists and define suitable programmes of study. More generally he would like to establish a minimum programme for students in astronomy, which would facilitate the exchange between the universities, as it is already done by the International Union of Mathematics. He emphasizes that the growing importance of astronomy requires that the didactics of astronomy should be developed.

Prof. L. Owren then spoke about the teaching of radio astronomy:

TEACHING OF RADIO ASTRONOMY

Leif Owren
(University of Alaska)

General

Most of our knowledge of astronomical objects and the universe is obtained from ground observations of light and radio waves through the two windows where the Earth's atmosphere is transparent to electromagnetic radiation. The division of astronomy into optical and radio astronomy is thus partly conditioned by instrumental considerations, and partly by the youth of radio astronomy as a field of science.

Ideally, the teaching of astronomy should not be dependent on the particular instrumentation or spectral window used to obtain the information, but aim at presenting a unified and balanced picture of astronomical knowledge drawing on all observational evidence.

A look at most available textbooks on astronomy will show that we are rather far from this ideal. In particular the elementary, descriptive type textbooks suffer badly from imbalance as they mostly emphasize the traditional results obtained by optical techniques with some tacked-on, scattered remarks on the not-too-recent radio results. But generally little attempt is made at an integrated presentation on this level where it could most easily be achieved.

Until the need for an unified approach is more generally recognized and adopted, it is unavoidable that radio astronomy be taught as a speciality subject on several levels and from diverse points of view. At the present time radio astronomy courses may therefore aim at (1) surveys of techniques and specific radio results, (2) more penetrating studies of individual aspects such as the generating mechanisms for radio frequency emissions and the related astrophysical and hydromagnetic conditions, and (3) practical instruction in radio instrumentation and observing techniques.

However, it behoves the radio astronomer no less than the traditional astronomer to present to the extent possible the speciality material in its proper perspective to the general body of astronomical knowledge.

1. *Surveys*

Radio astronomy survey courses lend themselves well for offerings at the senior undergraduate and early post-graduate level. Survey courses are equally accessible to students having either a physics or an engineering background, and are important for recruiting purposes. The recent, well-balanced textbook by Steinberg and Lequeux, 'Radio Astronomy', provides excellent core material for survey courses. The chapter headings of this book gives a complete programme for a survey, as follows:

(1) The role of the atmosphere
(2) Thermal radiation
(3) Simple radio telescopes
(4) Interferometers and aperture synthesis
(5) Spectral observations
(6) Mechanisms of emission of radio waves
(7) Radio emissions from the Sun
(8) Radio emission from the solar system
(9) Galactic radio emission
(10) Galactic radio sources
(11) Extra-galactic radio sources

From this general programme outline and the textbook mentioned, individual instructors can readily organize a survey course with such emphasis on, and elaboration of, specific topics as their personal preferences and the local situation indicate. It should be mentioned that a radio astronomy survey course offers an excellent opportunity for discussing on the elementary level the thermodynamic concepts of astrophysics including simple, illuminating applications of the principle of detailed balancing.

2. *Graduate (Post-graduate) Courses*

Graduate course offerings in radio astronomy will usually be concerned with a deeper study of a few of the subjects listed above, in the form of lecture or seminar series. The subject material may be drawn partly from the (few) available reference books and mainly from recent publications. The selection of material and topical emphasis will necessarily depend on the interests of the instructor and the field of research activity of the institution concerned.

There are, however, some areas where a radio astronomy course provides a particularly suitable approach to more general problems. Thus the study of the generating mechanisms for the non-thermal radio emissions involves directly the interaction of energetic particles with hot and cold plasmas pervaded by magnetic fields. Also, a radio astronomy approach is likely to produce a deeper understanding of the properties of electromagnetic fields, such as their vector character, the need for introducing the Stokes's parameters, and the effect of magnetic fields on the polarization. The interpretation of radio interferometer observations requires a thorough understanding of the coherence and polarization properties of electromagnetic radiation.

Alternatively, and in some cases, preferably, the graduate course offerings would be selected from the list of subjects given in Prof. Minnaert's 'Preliminary Report on the Teaching of Astronomy', and the contributions of radio astronomy integrated in these courses.

3. *Practical Radio Astronomy*

This is one of the most important areas of instruction in radio astronomy as the observational results can hardly be evaluated without some first hand practical experience with the observational problems and the effects of the receiving equipment on the noise-type signals passing through it.

While a practical course in radio astronomy may take many forms depending on the resources of the institution, the following outline of such a course carried through successfully with very limited laboratory equipment and funds could be of interest to some facing a similar situation.

A one-year practical course was given recently to a group of graduate students with partly physics and partly electrical engineering backgrounds whose practical knowledge of electronics varied from essentially none to quite comprehensive. The programme laid out for the course was to proceed from initial laboratory studies of practical techniques and fundamental concepts to the design and construction of a simple, twin-wave phase-switch interferometer for about 150 Mc/s. On completion the interferometer was to be used for observation of solar radio emissions and radio star scintillations.

The course involved one lecture or seminar session and one laboratory period weekly. The lectures and seminars were concerned with background material for the laboratory and observational work. The laboratory included:

(*a*) Instruction and practice in soldering techniques and equipment lay-out.
(*b*) Assembly of the required test equipment from kits.
(*c*) Experiment 1: Physical electronics—Laws of thermionic emission.
(*d*) Experiment 2: Radio noise—Minimum detectable signal of random noise type.
(*e*) Experiment 3: Measurement and design estimation of receiver noise figure.
(*f*) Design and construction of low noise r–f amplifiers for 136 Mc/s, either of the vacuum tube type (grounded grid or cascode), or the tunnel diode type, or a parametric amplifier, according to the initial level of experience of the students.
(*g*) Assembly and testing of the phase-switch interferometer, using a successful pair of the pre-amplifiers constructed and available local oscillator, main i–f, and phase-switch equipment (or a riometer), yagi antennas, and solid dielectric coaxial cables.
(*h*) Observations with the interferometer, and autocorrelation analysis of selected observations.

The instruction sheets for the Experiments 1–3 are appended for the benefit of those interested.

Dr M. H. Wrubel talked on teaching the use of computers to astronomers. Electronic computers have become an important astronomical tool in recent years; the next generation of astronomers will regard the use of electronic computers in much the same way as we regard desk calculations today. There are now many books in programming and a student can learn the fundamentals from these in a matter of a few months. It is best to start with an easy language (like FORTRAN or ALGOL) and to have a particular problem in one's mind.

While the teaching of programming is developing rapidly, even at secondary schools, the same cannot be said for the allied topic of numerical analysis, which at the present time is often considered by some mathematicians as outside the realm of their science. Nevertheless the techniques of applied mathematics are very important for the instruction of our students and for the future of astronomy (Example: the Henyey method !).—One role the proposed Commission on the Teaching of Astronomy can play is to cooperate with the International Federation of Information Processing Societies (IFIPS) which is also interested in teaching electronic computers to scientists.

In the general discussion, *Prof. L. H. Aller* pointed out that the training at undergraduate level should include a core curriculum in physics plus a year's course in general astronomy and astrophysics. There is an over-supply of people able and willing to use large telescopes while there is an acute under-supply of people trained in experimental techniques and instrumentation. There is also an urgent need for more good theoreticians.

Prof. L. Gratton stressed the significance of the Varenna summer courses. They are organized by the Italian Society of Physics, thanks to the broad mind of Italian physicists and to the personal efforts of Professors Righini and Gratton. If the IAU expressed its appreciation of the importance of these courses, perhaps the number of courses could be increased in the future.

Prof. E. K. Kharadze mentioned that in the U.S.S.R. the training of astronomers is specialized nearly from the beginning. The graduated student is already an expert in his particular field. Astronomy is being taught in close contact with research work and practical work at observatories. The training of astronomers in the U.S.S.R. is a combination of education at large astronomical centres with the organization of observatories and research work in national observatories in almost all of the republics.

Dr. W. Buscombe put forward the question whether it is more effective for astronomers in developing countries to undertake writing their own elementary textbooks, or to translate those manuals which have been found most effective among the larger nations.

Prof. T. L. Page reported on the educational activities of the American Astronomical Society. He stressed that (*a*) more astronomers should become aware of teaching problems and help with their solution, (*b*) the general public must be better informed about the goals of astronomical research. This can be done by public lectures, television, motion pictures, and popular publications, which will also help attract suitable students into our profession.

Prof. N. Boneff stressed the necessity to create a 'cosmic mentality' with the young people, because astronautics is the science of the future.

Miss W. Seitter thinks that it might not be out of place to consider the very techniques of teaching as well. By commanding the large auditorium without the help of a microphone, Miss Seitter proved her point that some amount of voice training would be highly desirable. Also speaking freely without depending on notes to a large degree, would be beneficial to teaching as well as to scientific meetings.

Prof. Minnaert concluded the discussion by reading two proposals for resolutions which were adopted unanimously. Their text is as follows:

1. The Members of the International Astronomical Union, present at the Hamburg meeting on the Teaching of Astronomy, strongly recommend to the Executive Committee to organize a Commission of the Union on this subject. For this they have the following reasons:

(*a*) A continuous progress of science is only possible, if new and better methods of teaching are found, and if these methods are adapted ever again to the development of modern science.

(*b*) Questions of teaching are of great importance for the recruitment of astronomers.

(*c*) Especially for countries where modern astronomy has still to be introduced, it is most useful to give a basic pattern according to which this might be done.

(*d*) The remarkable interest, shown for this preparatory meeting, shows that the teaching of astronomy plays a great part in the life and the work of many Members of the Union.

(*e*) All ten scientific Unions have their teaching Commissions; it is necessary that astronomy should have its place among them.

2. The Members of the International Astronomical Union, present at the Hamburg meeting on the Teaching of Astronomy, recommend to the Executive Committee that the Union should

co-operate with the other scientific Unions in the Inter-Union Commission on the Teaching of Science (IUCTS). This task could be entrusted to the new Commission on the Teaching of Astronomy or to a special committee within this Commission.

Dr Pauls showed a modernized version of an armillary sphere. Its use might shorten the time necessary to explain the basic concepts of spherical astronomy to students.

Dr K. Henize presented a motion picture on the solar eclipse expedition, organized by Prof. J. A. Hynek in 1963 in order to provide students with experience in planning observations and to use instruments.