55. — A COMPUTER PROGRAM
FOR NON-GREY STELLAR ATMOSPHERES

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At the Smithsonian Astrophysical observatory we are exploring the potentialities of the I. B. M. 704 digital computer in astrophysical applications. The present paper is a progress report on one aspect of a comprehensive program of research on stellar atmospheres being carried out under the guidance of Dr. C. A. Whitney.

My own program concerns non-grey equilibrium atmospheres for stars of intermediate temperature. The Poincaré-Lighthill variational technique, whose application to stellar atmospheres has recently been developed by Prof. Max Krook, will be used to find a temperature distribution that accurately satisfies the requirement of constant radiative flux. When this has been achieved we can compute theoretical color curves and bolometric corrections for stars with various surface gravities in the F5-K2 range. We will also explore the effect of variations in the helium ratio and metallic abundances on the energy distribution of a star.

We begin by computing a grey atmosphere with the temperature distribution specified by the Milne-Eddington approximation. Since any type of mean opacities can be easily introduced into the machine program, we are exploring several to see which provides the best first approximation to the correct constant flux. Our final results will, of course, be independent of the particular mean chosen. We have also been exploring the effect of the size of the integration steps and the effect of the starting depth on the results. The starting equations for the first two levels introduces a transient effect that damps out after 10 or 20 steps. In integrating the equation of hydrostatic equilibrium we have found a spurious oscillation in the pressure that can be minimized by the proper choice of weights in the numerical integration.
The results of the grey-atmosphere program are used as input for a second program that evaluates monochromatic optical depths, fluxes, and the mean intensities. We have written subroutines that compute the first and second exponential integrals, and the opacities as a function of frequency and temperature. For the negative hydrogen ion a combination of polynomials are used to approximate within 1 % the Chandrasekhar-Breen table for bound-free transitions and the new unpublished Ohmura-Ohmura table for free-free transitions.

The results of the second program are used as input for the third program, which will be used to obtain an improved temperature distribution. We will use the first order perturbation in Prof. Krook's new variational procedure. This Poincaré-Lighthill method differs from conventional perturbation methods in that perturbations are applied not only to the dependent variables, but also to the independent variable, in this case the optical depth.

A grey atmosphere with 100 steps is computed in about 30 seconds by the I. B. M. 704. Evaluation of 30 monochromatic fluxes each at 10 levels takes about 10 minutes of machine time.

From an iterative application of the three parts of our program we hope to obtain model atmospheres in which the flux is constant within a fraction of a percent. In this way we hope to get theoretical monochromatic fluxes and bolometric corrections that are much more accurate than any presently available. As a by-product of this research we will obtain a set of standard model atmospheres to supplement the few already existing.
DISCUSSION DES COMMUNICATIONS 49 à 55.

C. DE JAGER (49). — You estimated the optical depth of the temperature minimum in the solar photosphere ($\tau_{5000} = 0.1$) from the observation that the Fraunhofer spectrum changes into an emission spectrum near $\lambda = 1800$. I have made a similar computation leading to $\tau_{5000} = 7.10^{-4}(\approx 150 \text{ km above the solar limb surface})$.

J. C. PECKER (49). — Les calculs que j’ai effectués sont très grossiers ; le résultat est sans doute assez sensible au choix du modèle.

A. UNSÖLD (49). — In connection with the theory of the outermost layers of the sun and stars the conservation of the total flux in radiative equilibrium has been mentioned. One should remind that the existence of the solar corona is due to the fact that only 0.01% or less of the energy flux there is transported by mechanical means and not by radiation! The driving thermodynamical machine is of course the hydrogen convection zone. Its theory is still severely hampered because we have no adequate theory of the “Prandtl mixing length”. Mechanical energy is then carried outwards by various kinds of waves. Their propagation and dissipation (non linear effects of many interpenetrating waves) again presents many unsolved problems. So one should be aware that all theoretical predictions in our field must contain very considerable uncertainties.

W. LILLER (51). — I am most pleased to hear that MM. Hummer and Seaton are directing their attention towards the central stars of planetary nebulae. They are perhaps less well understood than any other type of star. Several years ago I calculated an atmosphere for a typical central star ($T_e = 45,000^\circ$, $\log g = 5.00$) and found that the amount of radiation available for ionizing hydrogen, as predicted by the atmosphere, was almost exactly equal to that given by the Planck function at a temperature of 45,000$^\circ$. It was gratifying to find this equality, upon which the Zanstra method depends. I anxiously await the results of MM. Hummer and Seaton.

J. C. PECKER (52). — L’existence de zones convectives pour les étoiles froides, et leur non-existence pour les étoiles chaudes devraient à priori conduire à des couronnes très faibles pour les étoiles chaudes (au-dessus de A5). Comment ce phénomène intervient-il dans les calculs de MM. de Jager et Neven?

C. DE JAGER (52). — As Mrs Böhm-Vitense showed, convection does not occur in stars with effective temperatures $\geq 6500^\circ$. The existence of coronas around the hotter stars has been assumed due to the mechanical energy flux generated in the turbulent region which occurs in rotating stars in the region where convection should occur according to Schwarzschild’s criterium (see Kippenhahn, Zs. f. Astrophys., 1959).

K. WURM (54). — M. Pottasch says that there is no test for the assumption that the continuous emission in diffuse nebulae originates from the two-photon emission of hydrogen. In the nebulae, after investigations of

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Rosino and Wurm, there cannot be found a correlation between the hydrogen and the continuous emission.

S. R. POTTSCH (54). — The best way to determine whether or not two-photon emission plays an important part in the continuous emission from diffuse nebulae is to measure the frequency dependence of the continuous emission. This has been done for the Orion nebula by Andrillat in the infrared region of the spectrum where the Paschen continuum is no longer a problem. His conclusion was that a measurable part of the continuum is due to two-photon radiation.

M. J. SEATON (54). — At the Liège dust meeting, I argued that some anomalies in Balmer intensities for the Orion nebula might be explained in terms of appreciable optical depths in the Balmer lines and continuum. Later, quantitative work by Pottasch has shown that some of my arguments require revision. The Orion filter photographs of Wurm suggest that atomic continua do not explain all of the continuous radiation of Orion.

On the other hand, Pottasch has made a rather convincing case for believing that the two-quantum radiation may account for most of the continuum in certain other diffuse nebulae, particularly those for which large Hα/Hβ ratios suggest appreciable Balmer optical depths.

J. RING (54). — I agree with Prof. Wurm about the errors of measurements of line-continuum intensity ratios using filters, or indeed any photographic technique. However I believe we can get good values from photo-electric grating spectrometers. What does Dr. Pottasch want to do? Is he using known values of Lyman continuum intensities to predict the visible continuum or vice-versa? Or does he want to measure both to test his two-quantum hypothesis?

S. R. POTTSCH (54). — The primary method I wish to stress for determining the Lyman continuum emitted by the O stars is the measurement of the Balmer line radiation, because observationally it is the best known radiation. I included the two-photon measurements to show their rather rough agreement with the deductions from the Balmer radiation.
SECTION VIII

CONSIDÉRATIONS THÉORIQUES
SUR LA PRÉDICATION DES SPECTRES
ULTRAVIOLETS LOINTAINS DES COMÈTES
ET DES AURORÉS POLAIRES