EXPLORING STELLAR ATMOSPHERES WITH A DESKTOP COMPUTER

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Received: October 26, 1992

Abstract

This paper describes the use of an interactive computer program for building models of stellar atmospheres, computing their radiation, and comparing their spectra with observed radiation from selected stars. The program is intended to supplement introductory courses in astronomy and astrophysics.

1. Introduction

Models of stellar atmospheres have held a key to many problems in stellar astronomy, such as the chemical composition of the universe, accretion discs and star formation, close binary stars, stellar winds, and mass-loss from stars. By examining the observable properties of theoretical models of stellar atmospheres, astronomers hope to infer the properties of real stars.

The atmosphere of a star contains all layers which may be seen from the free space outside the star. Heat radiation produced in the interior of a star must pass through an atmosphere which filters the radiation and adds features that are characteristic of conditions in the visible layers.

The program described in this paper will permit the rapid construction of simplified models for stellar atmospheres and it will introduce the user to some of the fundamental tools of modern astronomy: the classification of stellar spectra and the interpretation of stellar brightness and color in terms of the mass, radius, and luminosity of the star.

2. Mousing Around the Color-Magnitude Diagram

The color-magnitude diagram is one way to summarize the observable data on a star or a group of stars. Once we have selected a star, located it on the color-magnitude diagram, and have estimated its mass by one means or another we can start building a model.

This computer program will plot individual stars on a brightness-color diagram, which is also known as the Hertzsprung-Russell, or H-R, diagram. It is probably the most useful diagram in stellar astronomy, but it is a fact of astronomical life that two types of H-R diagrams are in common use - one by theoreticians and another by observers. The two types of H-R diagrams look very much alike. Along the horizontal axis, theoreticians would plot temperature, but the observers, who cannot measure temperature directly, must be content to plot a star's color or its spectral type. This program uses color, which is determined from the ratio of spectral intensity in two carefully specified wavelength bands. The most commonly used color is known as the B-V color of the star. (The letters stand for "blue" and "visual," and they correspond, respectively, to the blue and yellow-green regions of the spectrum. Measurement in the V band corresponds quite closely to the human eye.)

Along the vertical axis, observers plot absolute visual magnitude, that is, the magnitude the star would have if it were at a standard distance of 10 parsecs. (One parsec = 3.26 light years, the distance light travels in a vacuum in one year.) Theoreticians would plot the total luminosity of the star.

The stellar atmosphere program permits you to select a constellation on the screen, point with a mouse to a star in that constellation, and see the star plotted on the observers' brightness-color diagram. Your task is then to select a set of theoreticians' parameters and use the program to build a model atmosphere that imitates the real star. You do this by specifying numerical values for the basic parameters: radius, mass, total brightness, and distance. The program then evaluates the surface temperature and the acceleration of gravity, builds the model, and computes its color. The model is then displayed on the observers' brightness-color diagram alongside the real star you have selected. You may also plot its detailed spectrum.

The game is to adjust the theoretical stellar parameters until the observed data are matched. This match will give you the surface temperature of the star. If you know both the apparent and absolute magnitudes, the program will help you to derive distance and radius of the star.

In summary, observers and theoreticians use two types of color-magnitude diagrams, and the task of model stellar atmospheres is to translate one type of diagram into the other, permitting the observers and theoreticians to talk to each other.

3. Technical Matters

3.1 Specifying the Model

The user starts by specifying the physical parameters of the atmosphere, and the program computes the initial temperature and pressure distribution from the equation of hydrostatic equilibrium in one of three alternative ways:

1. constant temperature,
2. radiative equilibrium condition (corresponding to constant radiative flux),
3. mixing-length theory of convection where the radiative gradient is unstable.

The model evaluates the emitted radiation as a function of wavelength. It can be requested to compare emitted radiation with blackbody curves and compute observable quantities, such as photometric colors. The radiation field inside the atmosphere may also be displayed. After the initial model has been constructed, the user may adjust the temperature manually and ask for a new computation of the gas structure and the radiation field.

The program can hold two models at once, and the models may be graphically compared on the screen or with screen dumps.

3.2. Method of Calculating the Radiation Field

After the nature of the opacity has been defined and the pressure structure of the model has been established, the user may request the program to evaluate the radiation field in the atmosphere. The continuous opacity may either be gray (independent of wavelength), or it may be computed from hydrogen and helium. The thermal equilibrium (LTE) assumption is used to evaluate the level populations. If the user selects a grey gas, the program uses a frequency-integrated radiation intensity. In the non-grey case, the program divides the photon-energy spectrum into "bins" and evaluates the opacity and the emission at each depth. The radiation field is calculated with the two-stream approximation.

3.3. Output display

The program has the following types of output:

1. Plots of selected physical parameters (e.g., T, P, opacity, density, hydrogen ionization) as functions of depth may be superposed for direct comparison.
2. A graph of the emitted spectrum and comparison with blackbody radiation; the user may scroll through the spectrum and adjust the wavelength scale of the plot to zoom in on regions of particular interest, such as absorption lines.

Tables of physical parameters as functions of depth may be listed on the screen or printed.

4. Context of the Program

The program is intended for college students who are taking an introductory course in astronomy or astrophysics. It will be part of a broad undergraduate curriculum being developed by an international group of physicists known as the Consortium for Upper-level Physics Software (C.U.P.S.). The project is being funded by the National Science Foundation, I.B.M., and Apple Computer through George Mason University, and it will be published by J. Wiley. The final versions of the software will be prepared in Pascal code for both the Apple Macintosh and the PC lines of desktop computers, and it will be accompanied by brief texts.

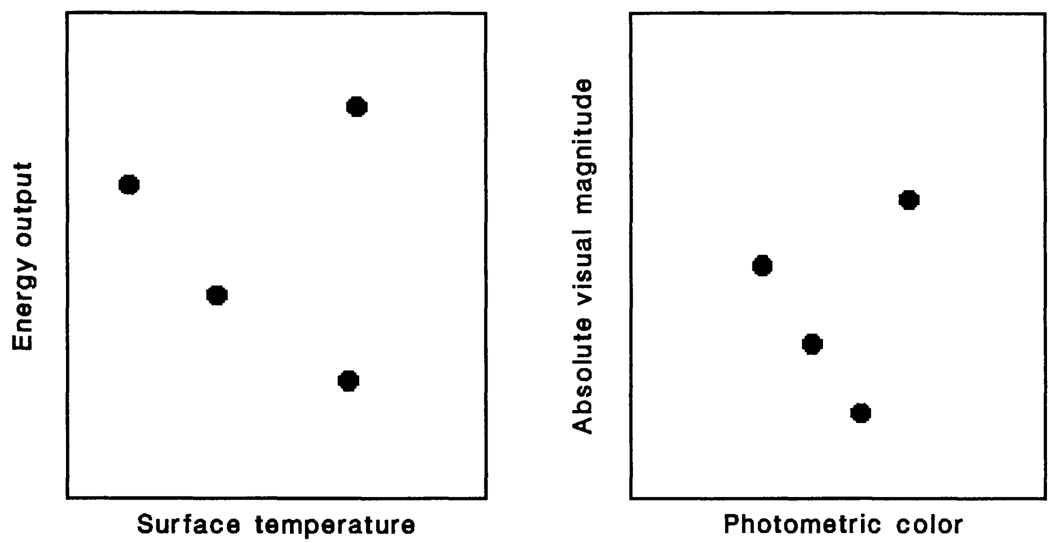

Figure 1. Hertzsprung-Russell diagrams according to the theoreticians' and the observers' parameters. Several stars are shown schematically, and their locations differ slightly in the two diagrams because they reflect different data.