USING COMPUTER SIMULATIONS WITH VARIABLE STAR DATA

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Abstract

Five desktop computer simulations for the modeling of stellar properties and the variations of eclipsing binaries and pulsating stars are described. Their relationships to the various stages of data modeling are indicated with a concept map. These simulations can be used for demonstrations, for homework, or for qualitative data analysis.

1. Background: The CUPS Astrophysics Course

A group of about 30 physicists and astronomers are developing interactive desktop computer simulations for upper level college courses. CUPS stands for Consortium for Upper level Physics Software. The project has funding from the NSF and IBM and is managed at George Mason University (Ehrlich 1992).

Each simulation will be accompanied by a text of about 40 pages describing the program and the underlying physics. There will also be exercises requiring use of the program, as well as suggestions how to modify the Pascal source code for special purposes. A particularly important feature of these programs, and one that does not come easily, is that they are interactive. Their interfaces have been made uniform, so that once a student has learned to run one of them, it will be relatively easy to move on to another. These materials (books and discs for PC-clones and Macintoshes) will be published by J. Wiles, starting in 1995, and are intended to be relatively inexpensive.

The astrophysics team has developed three sets of simulations. Most of them have to do with building models of various types of stars. The team members and their topics are as follows:

1. J. M. Anthony Danby (North Carolina State University): Binary Stars, Galactic Kinematics;
2. Richard T. Kouzes (Pacific Northwest Labs): Stellar Interiors, Stellar Evolution;
3. Charles A. Whitney (Harvard-Smithsonian Center for Astrophysics): Stellar Pulsation, Stellar Atmospheres.

Topics for the simulations were chosen on the basis of two criteria:

1. The physics should be accessible to upper level college students,
2. Using the simulations should involve the students in the types of activities that astronomers actually do.

2. Uses of the Simulations

The simulations were originally intended for use in conventional physics and astronomy courses, for demonstration and homework as an add-on to lectures.

However, these simulations could also be used in a less formal way to provide a rich source of challenges. Used with real data, they could put students into the mode of a scientist. Such data could be obtained by the student, perhaps in an earlier course. They might be obtained from the published literature, and they might also be unpublished data obtained from astronomers who would act as mentors. (As they stand, the simulations are probably not, in themselves, sufficiently sophisticated to provide publishable results, but this is only the first generation of desktop simulations.)

Suppose the students could acquire a set of real data in a fairly advanced stage of reduction - a light curve and radial velocity curve for an eclipsing binary, for example. They could be challenged to use the simulations to decode the data and find out the physical parameters of the stars. This work would be less formal than a standard course, or it could be done as part of a formal course. In either case, it would put more of the load onto the students and it would engage the students in building meaning for themselves.

The remainder of my discussion will be a brief outline of one way that some of the simulations might be used for modeling certain types of stars.

3. Introducing the Varieties of Stellar Data

Look up at the stars and imagine they are all the same distance from you. If one star looks brighter to your eye, then it is truly brighter.

Now put yourself back in time to the birth of the first stars in the galaxy. Some will be brighter than others; some will be redder and some bluer.

3.1. Color-magnitude diagram

If you make a diagram in which each star appears as a dot, and the height (distance along the y-axis) of the dot depicts the brightness while the distance to the right (along the x-axis) indicated its redness, you will have constructed a standard color-brightness or Hertzsprung-Russell diagram. If you confine this diagram to very young stars, you will find they lie on a single line. A star's position on the line is determined by the star's mass. So if you tell me the brightness of the star, I'll tell you its mass. Massive stars lie high on this line, and they are bluer. Stars of small mass lie lower on the line and they are redder.

But how does the star of a particular mass "decide" what color to have? And why are the stars of greater mass also bluer?

3.2. The stellar interior program

Dick Kouzes' program addresses this question by constructing models for stars on this age-zero line. The user chooses a mass and inserts an approximate guess for the temperature at the center of the star and tells the program to find a solution. The mathematics are a bit tricky because the construction of the model proceeds from the inside and the outside simultaneously. The process is aptly called "shooting," and if the shots don't quite hit at the midpoint, the program automatically adjusts the aim and tries again, repeating this aiming and shooting until it succeeds. When the model has been built, the program can display graphs of conditions inside the star.

3.3. The evolution program

If you could return to the imaginary sky millions of years later, you would find that some stars have become much redder. This behavior is illustrated by the stellar evolution program. The difference has to do with the chemical composition of the interior.

The stellar model program described above is confined to stars that are so young there has been no time of nuclear burning to affect the chemical abundances. The models are assumed to be chemically homogeneous, that is, to have precisely the same mixture of elements throughout the interior. As the star ages, the nuclear processes that create starlight will deplete the hydrogen, creating helium. As this occurs, the average mass of the atoms in the deep interior of the star increases. This alters the structure and causes the radius and luminosity to change. (The change of mass brought about by this process is trivial. Other types of mass-loss are probably important in certain stages of development, but they are not included in the simulation.)

Kouzes has provided a second program (stellar evolution), which shows certain aspects of stellar development, such as an infant star's approach to the main sequence and the early evolution of a juvenile star away from the main-sequence.

It is still impractical to carry out a realistic set of calculations of adult stars onto the giant branch with a desktop computer. But with the rapid increase of power we have seen in the past few years, who knows what will be possible in the next few years!

3.4. Stellar atmosphere program

A challenging feature of the color-magnitude diagram is the fact that observers and theoreticians who build models of the stars use different coordinates for making the plot. For observers, the x-axis is the surface temperature (T). This temperature cannot be directly measured. However, if the temperature of an atmosphere were the same at all depths, the relationship between color and temperature could be calculated from a mathematical relation known as the Planck law. Real stars deviate from the Planck law, and the deviations must be calculated from model atmospheres, taking into account the opacity of the material and the variation of temperature with height in the atmosphere.

The user puts in the mass, radius, and luminosity; the program computes the key stellar parameters surface temperature and gravity (T, g), and then proceeds to construct a model and find its spectrum. Theoretical (B-V) colors are derived from the ratio of flux in two wavelength intervals. So this program carries out the translation between (T, g) and the colors. In this way it makes possible a comparison of observations with theoretical models of the interior (see Whitney 1992).

3.5. Variable stars

Data on variable stars, when they have been "reduced" to a consistent scale and carefully plotted, can be used to derive parameters for the stars. This process is usually done by building a model in the computer and then comparing the properties of the model with the observed properties of the real star. Starting from what amounts to a pure guess, the numerical parameters of the model are adjusted in an attempt to improve the fit between the observations and the prediction of the model.

3.5.1. Eclipsing binaries

One of the simulations creates the light curves of detached eclipsing binaries in an arbitrary orbit, taking into account ellipticity of the stars, limb-darkening, and the reflection effect. The program also animates the orbital motion so the student can visualize the system while seeing the light curve being produced.

The program permits determining the relative radii of the stars, as well as the limb-darkening and the relative surface brightness.

3.5.2. Spectroscopic binaries

Another program creates the radial velocity curve (line of sight velocity) for a component in an arbitrary orbit. It shows the motion of the star around the relative orbit and it animates the displacement of the spectrum lines produced by the Doppler shift.

This program can be used to infer the relative masses of the components of a binary system. In conjunction with the eclipsing binary simulation, the program permits determining the true radii and masses of the star for which eclipses and velocities are known.

3.5.3. Pulsating stars

In its current version, this program computes the linear adiabatic modes for the envelopes of stars with prescribed mass, radius, and luminosity. The program solves for the mode frequencies and permits the user to generate motions with an arbitrary mixture of modes. It may be used to simulate Cepheids with bumps (Whitney 1991). Later versions will include non-adiabatic and non-linear effects.

4. Summary: Concept Map Showing how the Stellar Physics Simulations are Linked

The following diagram presents one way to illustrate the connections between stellar parameters and observed properties. Each box contains a "concept" and the arrows indicate relationships between pairs of concepts.

Study the pattern and see if you can add new concepts and reorganize the map so it has new meanings for you.

Building a concept map like this is a helpful way of integrating new ideas with one's prior conceptions. See Novak and Gowin (1984) for a discussion of concept maps as a way of starting from a list of words, organizing information, and building a structure of ideas about a domain. Research shows that this is a powerful learning device. This can also be an amusing game.

References

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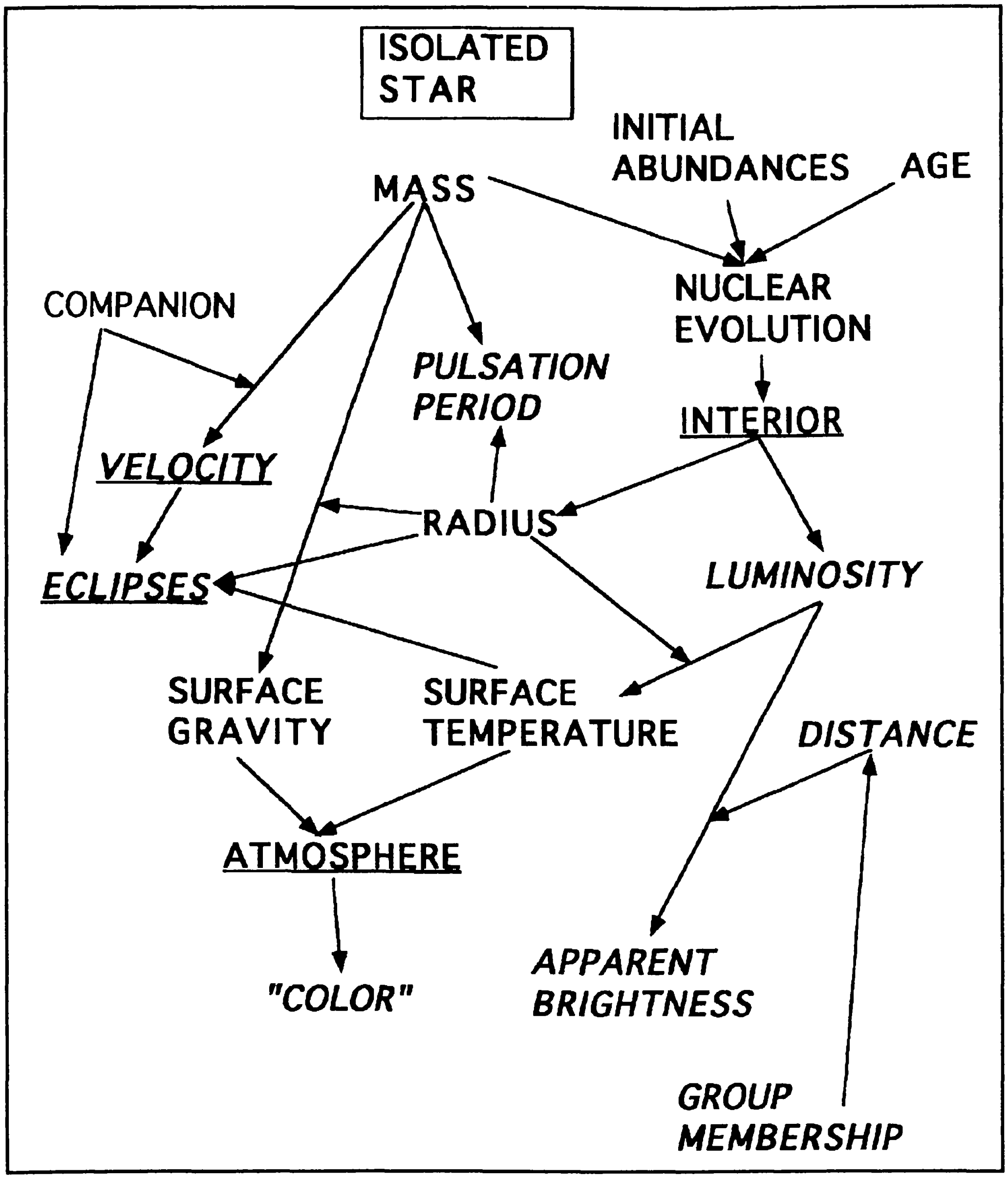

Figure 1. Concept map showing relationships among observed parameters (italics), derived quantities (roman), and computer simulations of the CUPS astrophysics course (underlined). See Novak and Gowin (1984) for an introduction to concept maps.