PHOENIX Inputs and Colors

Aaron Dotter

September 17, 2004

The Progress Report I put out in August raised a few questions about the PHOENIX model inputs used in our stellar evolution calculations. The following is, in part, an attempt to answer some of those questions.

1 Surface pressure

![Theoretical H-R diagram showing the red giant appearance obtained from three different sets of surface BC’s: Kurucz '90 (green), Eddington T-τ (blue), PHX (red).](image)

Figure 1: Theoretical H-R diagram showing the red giant appearance obtained from three different sets of surface BC’s: Kurucz '90 (green), Eddington T-τ (blue), PHX (red).

The first figure in report #1 showed the theoretical H-R diagram of two solar-calibrated models. One includes the PHX model inputs, the other uses the Eddington T-τ relation for the surface pressure and the low-T opacities of Alexander & Ferguson. The red giant
phase of the PHX model is noticeably straigher than the other model. The Kurucz ’90 surface pressure tables produce a result somewhere in between: the red giant phase of the Kurucz model is much like that of the T-τ up to about Log(L/L⊙) = 2 (corresponds to Log T ≃ 3.6) and then it more strongly resembles the PHX model until Log(L/L⊙) ≃ 2.75. Near the tip, the Kurucz model curves slightly towards cooler temperature.

Figure 2: Comparison of the tabulated surface pressures from Kurucz ’90 and PHX over the range of temperature and surface gravity relevant to the red giant phase of a 1 M⊙ star.

Figure 1 shows the H-R diagram of solar models using the surface pressures of T-τ, Kurucz, and PHX. To even the playing field, each of the models in Figure 1 includes the PHX opacities. Figure 2 is a comparison of the surface pressure from PHX and Kurucz over the range of log T and log g that are valid for the red giant phase of a 1 M⊙ star. The region where the evolution models differ in shape, from log T = 3.7 to 3.6, is also where the pressures differ most. As log T and log g decrease the log P values approach each other and the models are more or less parallel on the H-R diagram.

2 Opacities

A similar comparison between the PHX opacities and those of Alexander & Ferguson reveals no significant difference, particularly in the temperature and density range cor-
responding to red giants. Two isochrones constructed with the same surface BC but different low-temperature opacities will differ slightly in morphology due to the mixing lengths being unequal. The difference will be smaller than between two isochrones which use the same opacities but different surface BC's.

The main difference is the PHX opacities produce a RGB that is slightly less bright (by 0.1-0.2 mag) than a RGB produced with Alexander & Ferguson opacities. There is, however, one exception to this rule: when the PHX surface pressures are used the converse is true.

Figure 3: B–V as a function of temperature for three different color relations. The data points are the tabulated values with log g = 5.0 at bottom increasing upwards in steps of 0.5. The red line is an isochrone converted with the respective color table.
Figure 4: The Krishna–Swami T–τ relation gives an excellent fit to the RGB of M67. The PHX isochrone is plotted for comparison.

3 Colors

3.1 B–V

In the second figure from report #1, the isochrone drawn with PHX colors turns back to the blue near the tip of the RGB while the isochrone drawn with colors by Vandenberg & Clem (V&C) reach a maximum B–V and begin to fall off to higher V. The latter effect is due to the bolometric correction becoming much larger as the stars at the tip become increasingly red. The former effect is due to the \( T_{\text{Eff}} – (B–V) \) relation in the PHX color table. Figure 3 shows the \( T_{\text{Eff}} – (B–V) \) relation for three different color tables: PHX, Kurucz ’97, and V&C. In the figure, the B–V value at a given temperature is plotted as a function of \( T_{\text{Eff}} \) with log g increasing from the bottom up. Overdrawn are isochrones computed using each color table. The lower part of each isochrone (smaller B–V) is the low-mass main sequence. The higher portion is the red giant branch. Notice that while the Kurucz and V&C colors reach either climb to a higher B–V or level off at low temperature, the PHX B–V actually dips lower at 3500 K. This ”dip” is the source the hook at the top of the PHX isochrone in report #1.

3.2 A note on M 67

Figure 2 in report #1 included only isochrones made with the PHX model inputs. The best fit to the RGB in M 67 comes from the empirical Krishna–Swami relation. See Figure 4.
Figure 5: M 67 with V–K from the Montgomery et al. and the 2MASS database.

### 3.3 IR colors

The M67 CMD of Montgomery et al. (1993) has been cross-referenced with the 2MASS database to obtain JHK photometry for these stars. Figures 5 and 6 show M67 in V–K and J–K. Isochrones plotted were converted with PHX colors, each plot includes an isochrone with the PHX model inputs and the best fit isochrone from §4.

The Kurucz IR colors are similar to PHX except that the RGB drifts too far to the red above the bump.

### 4 Discussion

With only solar metallicity inputs to examine at this point, any conclusions that can be drawn are narrow in scope, but nevertheless here are a few.

Comparisons with M67 photometry in both the optical and near-IR suggest that the PHX models are too cool and dim on the RGB (Fig’s 4, 5, & 6) in most colors. The PHX B–V color is in agreement with neither observations (Report 1) or other color conversions below ~4000 K (Fig. 3). The PHX B–V conversion tends to create an RGB which is to cool at the base but to hot near the tip (and then there is the blue-ward hook).

Since the end goal, as far as isochrones are concerned, is to make the best possible match with observations it is clear that some work needs to be done to improve our results. Comments on the contents of this report would be greatly appreciated, especially in the cases of the surface pressures (Eddie) and colors (Guy & Eddie).
Figure 6: M 67 with J–K from the 2MASS database.