

A Test of Stellar Evolution Theory on the Red Giant Branch

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Initial studies of the globular cluster NGC 2808 indicated a significant lack of red giant stars (Sandquist & Martel 2006) near the tip of the red giant branch (TRGB). From this observation, two possible explanations were proposed. One was an underestimation of neutrino emissions in theoretical models, while the other involved strong mass loss from the stellar atmosphere. This study of 47 Tucanae was performed to provide data to test the theories. However, this study uncovered an unexpected surplus in the number of red giant stars near the TRGB.

Introduction

As a star like the Sun nears the end of the red giant phase, one of two possibilities occurs. If the star has sufficient mass, the core contracts and heats up enough to fuse helium, undergoing a helium flash. A helium flash is the point where the stellar core becomes so heated due to gravitational contracting that it can suddenly fuse helium. It is the point of termination for the red giant branch. However, if enough mass is lost, the star does not undergo the helium flash, but instead becomes a helium white dwarf.

As the star nears the point where it will undergo the helium flash, it climbs upward along the red giant branch (growing brighter) in the Hertzsprung-Russell (H-R) diagram. After the helium flash, moves to the horizontal branch and begins ascending the asymptotic giant branch (AGB). Stars in a globular cluster follow this path in a very specific manner and can be easily identified. However, in NGC 2808 there were fewer observed stars on the red giant branch (RGB) of the H-R diagram than expected. Sandquist & Martel (2006) proposed two theories for the lack of RGB stars were proposed.

The first theory suggests that neutrino emission rates would speed up the evolution of the stars by removing energy from the core at a faster rate than currently assumed. By speeding up the progression along the red giant branch, stars would spend less overall time in the final phase, leaving of fewer stars near the tip of the red giant branch.

Another explanation for the lack of red giant branch stars is that they never reach the tip of the red giant branch in the first place. Some models suggest that mass is lost at a much faster rate than previously assumed. This loss of the material from their surface diverts stars from the red giant branch, exposing the hotter stellar interior and moving the stars blueward on the H-R diagram. This diversion would prevent the He flash from ever occurring, resulting in a planetary nebula and a He white dwarf.

47 Tucanae was chosen for three main reasons. First, the cluster is relatively well observed, meaning that there is plenty of data to use for the purpose of this project. Secondly, 47 Tuc is a cluster where the RGB stars lose relatively little mass. Examination of the horizontal branch shows a small cluster of stars near the RGB, which indicates low mass-loss as opposed to a HB that is more spread out. This property allows us to more easily test the neutrino theory. Finally, 47 Tuc is a very massive cluster, which allows us to collect a large sample of stars, allowing more stringent statistical tests.

Observations and Data Reduction

Since 47 Tucanae is only visible from the southern hemisphere, direct observations were impossible from San Diego for this project. However, previous data had been taken by both NASA's Hubble Space Telescope and other sources. We began by taking point spread function and aperture photometry from images taken by the Hubble. This data was taken in both V and I bands of the spectrum and provided fairly clear data to work with when used to produce a Color Magnitude Diagram (CMD). After the photometry was taken, the data was reduced by removing objects that weren't stars or were poorly measured (with a sharpness value greater than ± 0.3 or a χ^2 value greater than 4). Next, the RGB, Asymptotic Giant Branch (AGB), and Horizontal Branch (HB) were

separated in order to isolate the TRGB for further study. This data, however, was ultimately set aside because the RGB in V and I bands is not monotonic with luminosity (see Figure 1). This would have represented a problem during later tests with theoretical models. The data, however, will still be useful for future work involving the cluster core.

Instead of continuing with the Hubble data, we used the online 2MASS database for data in the J and K bands. In these bands, the RGB curves less and remains ultimately monotonic throughout its entire length. The first step was to remove the heavily crowded stars. This was done by simply excluding all stars within $240''$ of the center of the cluster. Next, the data was separated into groups representing the RGB, AGB, and HB. Finally, we identified all known variable stars from the TRGB (see Figure 2) using the variable star list given by Lebzelter & Wood (2005). The reasoning behind this separation comes from Montegriffo et al. (1995), who states that many, if not all of the variable stars located at the TRGB are actually AGB stars.

Considerable emphasis was placed on separating the AGB stars and the variables from the RGB because the data-to-model test is particularly sensitive to variations in the number of stars at the TRGB. This is because there are so few stars at the TRGB.

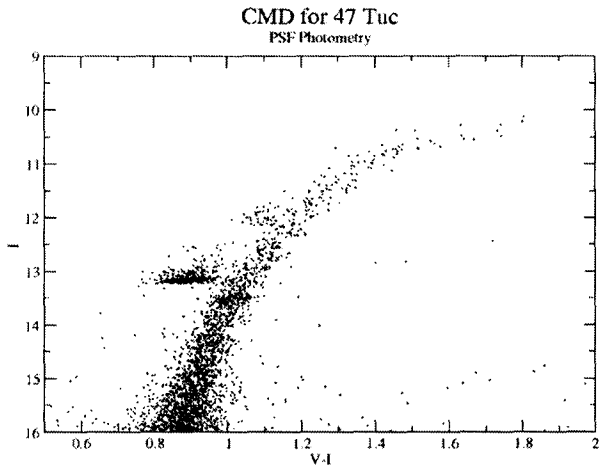


Figure 1: CMD Red Giant Branch of 47 Tuc using I band and $V-I$ color. The non-monotonic curvature of the RGB can be seen.

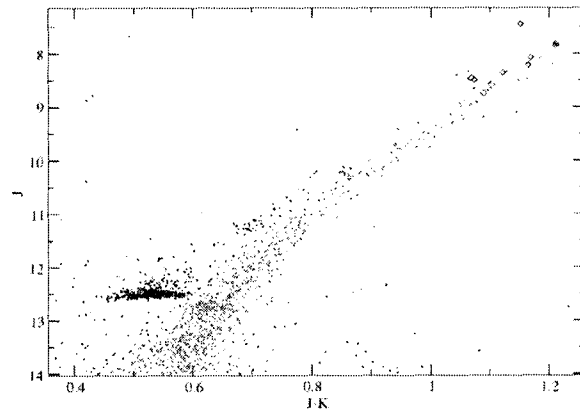


Figure 2: CMD Red Giant Branch of 47 Tuc. Grey points represent RGB stars, black points are AGB stars. Diamonds represent variable stars.

Analysis

The analysis involved two main steps. The first was to compare the various testing models to one another, and the second was comparing the testing models to the data. We compared the models to one another by plotting the running sum of TRGB stars against a decreasing (J) magnitude all on the same set of axes. Before comparing them, they first had to be adjusted to each have their RGB tips begin at the same point (see Figure 3). Each line in the figure represents a different testing model. As can be seen clearly, the strong correlation between the various models indicates that the age and metallicity of the cluster does not affect the physics underlying the models.

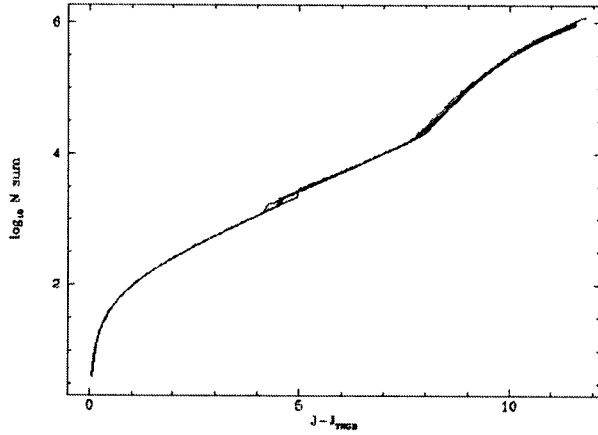


Figure 3: Comparison of theoretical models. The tight correlation implies metallicity and age do not alter the physics. The three closer lines seen at the bump are the models varied with age. The farther two are the models varied with metallicity.

After the models were compared to one another, they were compared to the data. We initially started with the $Z = 0.004$ metallicity and an age of 12 Gyrs. However, this model did not match well, specifically at the "bump" where there is a large cluster of RGB stars near where the HB resides at $J \approx 12.75$. We then adjusted to a Z of 0.008 instead, which matched the faint stars better. We then aligned the theoretical and the observed data horizontally at the TRGB and vertically at a point just brighter than the bump using values taken from Bellazzini et al. (2004). In an effort to produce the most reliable sample, we reset both the data and the model to begin the running sum count at the first star just fainter than the dimmest variable giant star on the CMD. This should have eliminated any effect that any residual variable AGB stars would have had on the model; however a net surplus of RGB stars remained.

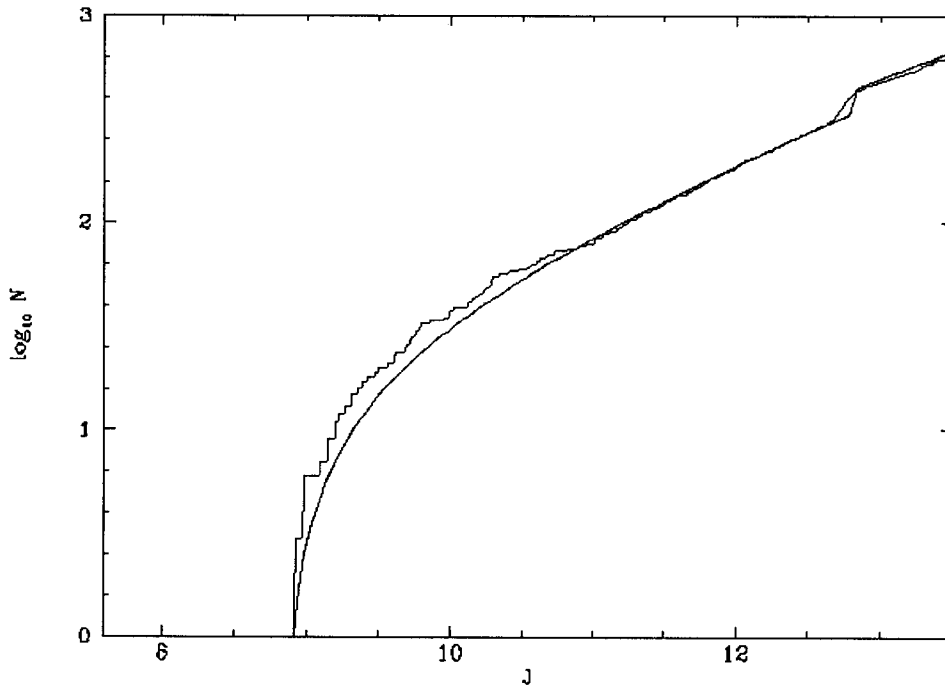


Figure 4: Running sum vs. J magnitude comparing theory to the observed data. The net surplus can be seen near the TRGB. The shown theory line has metallicity factor of $Z=0.008$ and age of 12 Gyrs.

A Kolmogorov-Smirnov (K-S) test was performed on the model and data to see if the surplus of stars represented a significant difference. (A K-S test compares the distributions within two datasets and tries to quantitatively measure if they differ significantly.) The results are shown in Table 1 below. The minimum luminosity (J_{\min}) was varied in order to determine the point of maximum difference

between the theory and the observed data. The P value represents the probability that the theory and the model came from the same distribution. Hence at the point of maximum difference, where $J_{\min}=11.0$, there was just a 3% possibility that there was no significant difference between theory and data.

Table 1: K-S Test Results

J_{\min}	D	P
12.6	0.037	0.785
12.4	0.043	0.708
12.2	0.053	0.554
12.0	0.060	0.485
11.8	0.075	0.316
11.6	0.084	0.272
11.4	0.098	0.206
11.2	0.138	0.048
11.0	0.157	0.035
10.8	0.101	0.413
10.6	0.112	0.382
10.4	0.091	0.700
10.2	0.121	0.489

Conclusions:

With the surprising net surplus of stars found at the TRGB, we cannot conclude which theory for the deficit of RGB stars in NGC 2808 (if either) is correct. The surplus cannot be explained by the excess mass-loss theory, since high mass-loss stars never reach the TRGB in the first place, but are instead diverted left along the CMD. Likewise, the surplus cannot be explained by the neutrino theory because that would imply that there are different neutrino emissions from the cores of red giants in different clusters. This is not expected from physics theory.

One possible explanation for this surplus is simply that there were additional AGB stars that were not identified and removed with the rest during the data reduction phase. Perhaps using other sources of more precise photometry, a more thorough study could be done to more accurately weed out additional AGB stars from the RGB, hopefully resulting in a strong check of this result.

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References

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