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Mass Loss from Red Giant Stars in Globular Clusters

PhD thesis

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Introduction

Mass loss plays an important role in stellar evolution. The amount of mass loss strongly depends on the stage of stellar evolution. Red giant stars have significantly higher mass loss rates than stars on the main sequence. Many red giant stars can be found in globular clusters, which appear in the halo of the Milky Way. This helps the investigation of mass loss, because nearly hundreds of red giant stars at the same distance can be observed at the same time. Here, I give an overview of my high resolution spectroscopic observations and semi-empirical models to calculate mass loss rates of red giants stars.

In the first part of my thesis, I briefly explain the stellar evolution and mass loss processes. In the second part I show my observations with Hectochelle on the Multi Mirror Telescope (MMT), and discuss the results from the statistical investigation of line profiles. In the third part, I give an overview of how I determined the mass loss rates from detailed line profile modeling.

Goals

The goals of my thesis are the following:

- To determine how the structure of the chromosphere of red giant stars depends on effectiv temperature, luminosity and metallicity from high resolution spectra of Hα and Ca II K.
- To evaluate the mass loss ratio of selected stars from semi-empirical modeling of the Hα line and to determine a possible dependence of mass loss on the physical parameters of stars.

Research Methods

Observations

Observations of Hα in a total of 297 stars on the red giant branch (RGB) and asymptotic giant branch (AGB) in M13, M15, and M92 were obtained in 2005 May, 2006 May, and 2006 October with the Hectochelle on the MMT with a spectral resolution of about 34,000. Only targets brighter than 15.5 magnitude were selected. Three order separating filters were applied: OB25 (Hα, region used for analysis $\lambda\lambda$ 6475 − 6630), Ca41 (Ca II K $\lambda\lambda$ 3910 − 3990), and RV31 ($\lambda\lambda$ 5150 − 5300). OB25 and Ca41 filters gave 155Å centered on the principal spectral features in Hα and 80Å in Ca II H&K. The basic image reduction were done with the IRAF software package.

Radial Velocity Measurements

To measure accurate radial velocities I chose the cross-correlation method. The Hα spectra of the targets were also cross-correlated against several hundred spectra calculated with the ATLAS code, covering temperatures between 3500 and 7000 K and metallicities between [Fe/H]=−2.5 and +0.5. The region selected for the cross-correlation spanned 6480Å to 6545Å purposely omitting the Hα line. For stars in M13 and M92, the spectral region on the RV31 filter between 5150 Å and 5300 Å was chosen, because it contains several hundred narrow photospheric absorption lines, thus the cross-correlation function is narrower than from the Hα region.

The determined radial velocities agree with the literature within a km s^{-1}. I find the average radial velocity of the three clusters to be: $-243.5\ \pm 0.2$ km s^{-1}of M13, $-105.0\ \pm 0.5$ km s^{-1}of M15, and $-118.0\ \pm 0.2$ km s^{-1}of M92. Altogether 6 stars in M15 were observed at least twice and showed velocity changes larger than 2 km s^{-1}, which could indicate these stars are binaries. In M13 and M92, only 2 stars in each showed radial velocity changes. One of them, L72 in M13, is a well-known pulsator, which could acount for the velocity variation.

Line Statistics

Differences found in the profiles of the Hα line give insight into the atmospheric structure and dynamics. Stars which are physically larger generally show more emission. Two methods have been used for the identification of Hα emission. The first selects stars with flux in the Hα wings lying above the local continuum. For the next method, I selected 8 stars with no emission and of different colors and luminosities to make a template. This template was then subtracted from the observed spectra. The stars identified with Hα emission are the same with both methods.

If movement is present in the atmosphere, then the absorption lines become asymmetric due to the Doppler-effect. If this movement in inward, the core of the absorption line will be redshifted, if it is outward, it will be blueshifted. I could identify movement in the chromosphere by measuring the line asymmetry using a line bisector. The difference between the centers of the line core and of the line near the continuum level gives a measure of the atmospheric dynamics through the chromosphere. To accomplish this, the line profile was divided into 20 sectors in normalized flux. The top sector was usually close to the continuum in the normalized spectrum, the lowest sector was placed just above the lowest value of the line. The actual position of the top and the lowest sector depended on the S/N ratio of the spectra

Models for the Hα Line

For the emission line calculations, I changed the parameters at the outer depths of the atmosphere to represent a chromosphere with the temperature increasing linearly with decreasing mass column density. For every temperature-mass column density distribution, I solved the non-LTE radiative transfer and the statistical and hydrostatic equilibrium equations, using the program PANDORA. I computed the non-LTE populations of a 15$-$level hydrogen atom to get the Hα line. Calculations were carried out in two phases for all models: in the first phase a plane-parallel approximation was used in order to calculate the scale of the atmosphere and the total hydrogen density. After this, the plane-parallel atmosphere was replaced with a spherical atmosphere with the same stratification, and this spherical model was used to calculate the emergent spectrum. Then, the regions where the core and wings of the Hα line are formed were put in motion. I constructed velocity distributions in order to produce asymmetrical line profiles to match the observed line asymmetries. This velocity field is included when calculating the line source function.

Results

1. In M15, spectra of 29 stars with Hα emission were obtained in both 2005 and 2006 out of 110 red giants. All but two of these stars showed significant changes in the line emission which either appeared, or vanished, or changed asymmetry. This also changed the lower luminosity limit of Hα emission on the RGB between observations. I observed a total of 123 different red giant stars in M13 and found 19 with Hα emission. In M92, I found 9 stars with Hα emission out of 64 objects. For these two clusters, the configurations were chosen to eliminate stars already observed in order to achieve full coverage of the potential targets. The number of stars observed twice for M13 and M92 was very small, so comparison was possible for only two of them in M13 and three in M92. The emission of these stars also changed between observations. Hectochelle spectra of M13, M15, and M92 show Hα emission to occur on the red giant branch in stars with T_{eff} 4500 K and $\log(L/L_{\odot}) > 2.75$. AGB stars exhibit Hα emission to lower luminosities. Ca II K emission extends to lower luminosities than Hα both on the RGB and AGB. The asymmetry in the Ca II K core in M15, where measurable, may differ from the asymmetry measured in the Hα wings perhaps due to time variability or different line-forming regions. Considering 3 clusters, spanning [Fe/H]=-1.54 (M13), to [Fe/H]=-2.3 (M15, M92), I find no systematic dependence of the presence of Hα or Ca II K emission from red giants on cluster metallicity. Stars in M15 have Hα emission wings that vary in time so that the magnitude of the faintest giant showing emission changes among the different dates of observation.

2. Asymmetric Hα cores show that chromospheric material is flowing out from stars brighter than log $(L/L_{\odot}) \sim 2.5$ and the speed of the outflow increases with increasing luminosity. The Ca II K_3 absorption features exhibit higher velocities than Hα suggesting accelerating outflows in the chromospheres. This outflow may represent the onset of mass loss, and the luminosity at which the outflow begins is similar for all metallicities. The sensitivity of

Hα to mass motions decreases for $T_{\rm eff} < 4000$ K causing the coolest giants in M13 to exhibit little or no outflow in this line. AGB stars near $\log\ (L/L_\odot) \sim 2.0 - 2.7$ have bisector velocities (10–15 km s^{-1}) comparable in value to those at the tip of the RGB and also exhibit larger changes in velocity between observation than the RGB stars (6–8 km s^{-1}). I take this as evidence of more substantial and episodic mass outflow on the AGB. Faster outflows are found in the metal–poor M15 and M92 than the metal–rich M13 objects. While outflow velocities of RGB stars do not depend on cluster metallicity, AGB stars show faster outflows in M15 and M92, than AGB stars in the more metal rich cluster M13. I find no differences in chromospheric signatures in the profiles or the presence of Hα and Ca II that can resolve the 'second-parameter' problem for the paired clusters, M15 and M92. Also, bisectors velocities are very similar in both clusters. Twelve stars identified in *Spitzer* observations as dusty IR sources and AGB stars have radial velocities consistent with cluster membership. Two stars identified as dusty red giant stars show no difference in mass loss rate from other red giants. The similarities in Hα line profile characteristics between the *Spitzer* sources and other red giants in M15 suggests the IR emission attributed to circumstellar dust must be produced by an episodic process. I conclude that the M15 giants are not currently undergoing an episode of dust-production.

3. An expanding velocity at the top of the atmosphere was required for every star in order to match the Hα core. The largest outflowing velocity reached 19 km s^{-1}, usually larger by factors up to 10 than indicated by the bisector velocity. In the region where the Hα emission is formed, the velocities can change direction, indicating the presence of pulsation. The calculated mass loss rates are near $\sim 10^{-9}$ $M_\odot$ yr^{-1}.

4. Chromospheric modeling of the Hα line in several clusters demonstrates that the mass loss rate increases with increasing luminosity and decreasing effective temperature of stars on the red giant branch. All stars modeled down to 2 magnitudes below the RGB tip show outflowing material suggesting that mass loss is a continuous process. The more metal-rich stars have a higher mass loss rate than the metal-poor stars. The calculated mass loss

rates from the Hα profile give values that are an order of magnitude less than those estimated from the Reimers, Schöder, and Origlia relationships. Differences are larger at higher luminosities. The Hα mass loss rates and the Origlia relationship give a very similar shallow dependence on luminosity. At the top of the RGB, for stars brighter than log $(L/L_{\odot}) = 3.3$, the Hα line may not be adequately sensitive to the mass loss rate; the models suggest lower mass loss rates for these objects. K757 (M15) shows a factor of 6 mass loss−rate change in a time span of 18 months (from 5.7×10^{-10} M$_{\odot}$ yr^{-1} to 3.0×10^{-9} M$_{\odot}$ yr^{-1}). A smaller change occurred in two other stars, K341 (M15) and L72 (M13), where the mass loss difference was nearly a factor of two. This shows that large changes in the stellar wind can occur in only one and a half years. Considering 50 Myr that these stars spend on the RGB, with 3.0×10^{-9} M$_{\odot}$ yr^{-1} mass loss rate, a star will lose about 0.2 $M_{\odot}$ before reaching the HB. This is in good agreement of stellar evolution theories.

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