CHROMOSPHERIC EMISSION FROM RED GIANTS IN THE OPEN CLUSTER NGC 6940

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ABSTRACT.
The observation of the Ca II H and K lines in red giants in NGC 6940 allows the strength of chromospheres and their behavior to be evaluated in a population whose evolution is well understood. Spectra in the Ca II lines have been obtained for giant stars in this cluster. Emission reversals are present in some objects. The absolute flux in the chromospheric emission is determined as a function of effective temperature for stars on the red giant branch. The stellar surface flux in the Ca II lines decreases smoothly with increasing $(B - V)$ in contradiction to model predictions.

1. Introduction

The decay of magnetic activity in cool stars and the influence of winds in angular momentum loss can be assessed through the strength and profiles of the Ca II lines (λ3967, λ3933). Observation of Ca II in red giants in cluster stars allows the behavior of chromospheres to be evaluated in a population whose evolution is well understood. Such studies can be used to test the conjecture that activity is dependent on stellar effective temperature and mass (e.g. Pasquini & Brocato 1992). NGC 6940 is an intermediate age cluster containing clump giants, bright red giants, and composite binaries. Age estimates range from 0.6 Gyr (Carraro & Chiosi 1994) to 1.9 Gyr (Thogerson et al. 1993).

2. Observations and Calibration

Echelle spectra in the Ca II lines have been obtained for 74 stars in NGC 6940 using HYDRA (a fiber positioner with bench spectrograph) at the 4-m telescope at the U.S. Kitt Peak National Observatory in June 1994. The multi-object capabilities of this instrument allowed 18 red giants, including five clump giants, to be observed simultaneously. A number of main sequence stars and non-member hotter stars were also included. The targeted red giants generally have a membership probability $\geq$ 80% based on proper motions (Sanders 1972) and confirmed by CORAVEL radial velocities (Mermilliod & Mayor 1989). The visual magnitude of the stars in this target field varied from V = 9.2 to V = 13.2, with observed B–V colors ranging from +0.2 to +1.8. Fig. 1 shows the color-magnitude diagram of our target stars individually corrected for reddening (Larsson-Leander 1960), and assuming $(m - M)_0 = 10.356$ (Janes & Phelps 1994).

To isolate the Ca II lines, an order-separating interference filter was used yielding a free spectral range of 3860–4025Å; the spectral resolution of 0.17Å was measured by the

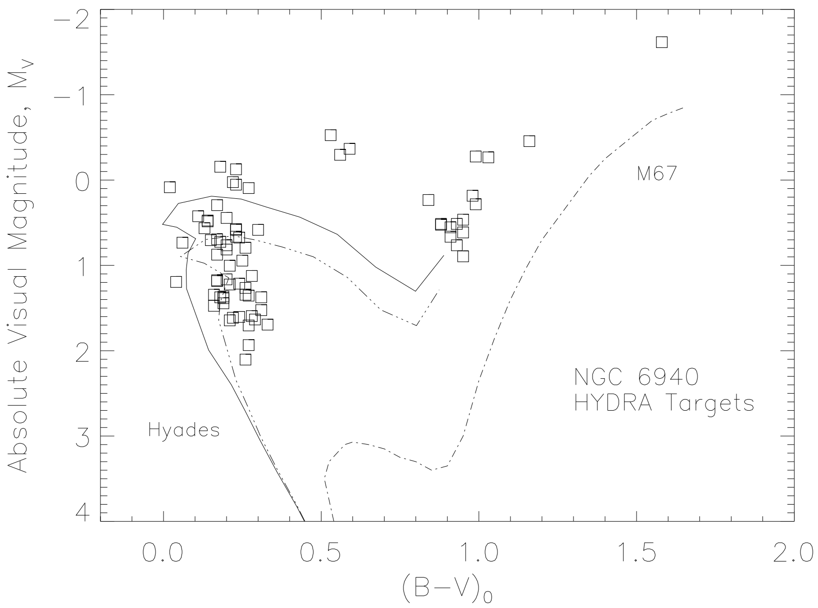

Fig. 1. Color-magnitude diagram of NGC 6940 indicating the stars observed by HYDRA. Isochrones for M67 (Tripicco et al. 1993) and the Hyades [600 Myr (solid curve) and 800 Myr (dash-dot curve); VandenBerg 1985] are shown.

FWHM of the Th-Ar comparison lines. Spectra were extracted from the CCD images using the HYDRA packages of IRAF. Four exposures of 3600 s each taken on 26 June 1994 were coadded to produce the final spectra.

Emission cores of the Ca II lines are readily apparent, as is their dispersion in strength. For example, two clump stars (identified by Mermilliod and Mayor 1989) VR101[1] $[V_0 = 10.82, (B-V)_0 = 0.95]$ and VR108 $[V_0 = 10.59, (B-V)_0 = 0.84]$, practically identical in color, have emission fluxes differing by a factor of four (Fig. 2).

The spectra were calibrated by using the absolute spectrophotometry of Gunn and Stryker (1983). The ratio of the H and K emission cores (measured over 2Å) to a 20Å continuum band in our target stars was then normalized to the Gunn/Stryker fluxes for giant stars of the same value of $(B-V)_0$. The emission flux at the star (Fig. 3) was obtained using the relation between $(B-V)_0$ color and apparent angular diameter from Barnes et al. (1978). An extended discussion of this method is contained in Dupree et al. (1997).

3. Conclusions

1. Chromospheres are present in all of the observed red giants, as indicated by their Ca II emission.

[1] Here the catalogue number VR is the identification by Vasilevskis & Rach (1957).

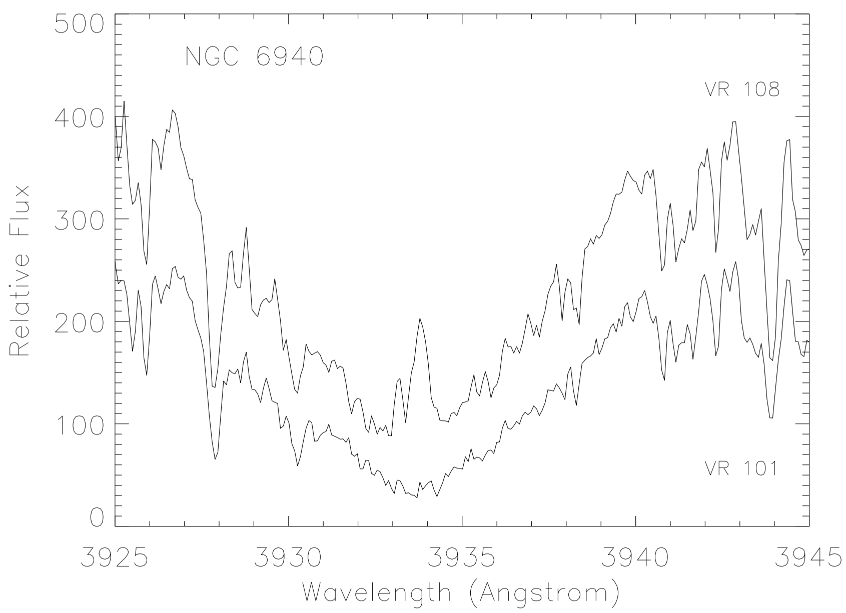

Fig. 2. Detail of the the Ca K profiles in VR 101 and VR 108. These clump stars are almost twins, although the chromospheric flux differs by a factor of 4.

2. The well-developed clump giants possess strong Ca II emission fluxes indicating that chromospheric activity continues into the helium burning phase.

3. Position in the color magnitude diagram is not a unique determinant of chromospheric activity as demonstrated by comparison of the clump stars VR101 and VR108 (Figure 2) which show a disparity in Ca II flux levels similar to the Hyades giants. The spread in emission level of the Hyades giants in the chromosphere, transition region and the corona (Stern et al. 1981) has been attributed (Baliunas et al. 1983) to the presence of magnetic activity cycles. These data will be combined with others in our cluster program to define the flux levels with stellar evolutionary mass.

4. The smooth gradual decay of Ca II surface flux with decreasing effective temperature is not in agreement with model predictions. These models assume that angular momentum is conserved, rigid body rotation, and the moment of inertia changes due to stellar evolution. Further studies to define the behavior with stellar mass, and to detect evidence of mass loss should place tighter constraints on the models.

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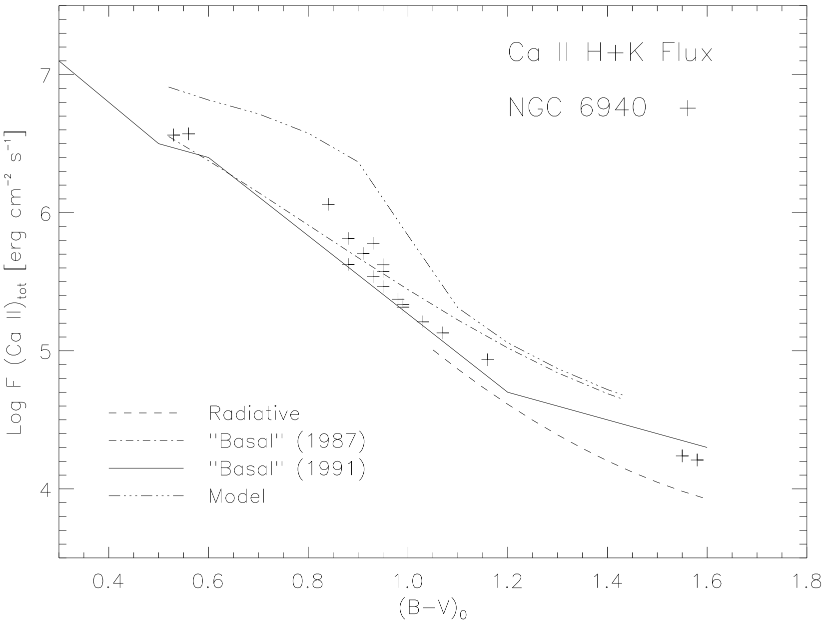

Fig. 3. The total Ca II $(H + K)$ stellar surface flux for the NGC 6940 giants. the curve marked "Radiative" derives from Kurucz radiative models of giant stars (no chromosphere); the curves marked "Basal" refer to estimates of a "basal" flux contribution (Rutten 1987; Rutten et al. 1991). "Model" refers to the predicted Ca II total flux for a $2M_{\odot}$ star (Rutten & Pylyser 1988).

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