Chromospheric Activity in Old Clusters

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ABSTRACT.

Observations of chromospheric activity in old clusters are presented, with emphasis on the most recent results. In particular, the solar age, solar metallicity cluster M67 is discussed in detail. By comparing chromospheric fluxes of giants belonging to different clusters it is shown that activity strongly depends on stellar effective temperature, but likely also from a second parameter. The presence of chromospheres in Globular Clusters (GC) luminous giants is now well established, and evidences exist that these stars may also undergo significant mass losses. The potentiality of two new ESO instruments on the study of chromospheric activity in old clusters is briefly reviewed.

1. Introduction

By studying chromospheric activity in old clusters (e.g. clusters older than the Hyades), several interesting astrophysical topics can be addressed. For example, the determination of the activity level in main sequence stars belonging to clusters of different ages would allow a full investigation of the age-activity relationship. Since the early work of Wilson and Skumanich (1964) it is known that young main sequence stars are more active than old ones, and this relationship has been confirmed by a number of studies of field objects (Soderblom et al. 1991). It is worth noticing, on the other hand, that the age-activity relationship is based only on one well studied old star: the Sun. Sofar no state-of-the-art data exist on chromospheric activity in main sequence stars in old clusters, for which only recently observations of *evolved* objects are becoming available.

While chromospheric activity in main sequence stars is at least qualitatively explained via the stellar dynamo mechanism (Noyes et al. 1984), the mechanisms powering activity in evolved stars are still under discussion, and it is not clear, for instance, which stellar parameter(s) is really driving activity in giants.

The study of chromospheres has implications beyond stellar activity. GC giants, for instance, are expected to loose a considerable fraction of their mass along the RGB, and our understanding of the chromospheric lines in these stars will have direct implications on stellar evolution theories.

Finally, being chromospheres linked to the presence of the subphotospheric convective zone, the study of the chromospheres in evolved stars will help in understanding phenomena like deep mixing which are responsible, among others, of the unexplained drop of Li abundance in RGB stars (Pilachowsky et al. 1993, Pasquini and Molaro 1997).

The body of published observations of chromospheric lines in old clusters stars is very inhomogeneous and in some notable case, almost not existent. Thanks to the use of large telescopes and multi-object facilities, this situation may rapidly evolve (see, e.g. Barrado et al. these proceedings).

2. Chromospheric emission: which parameters?

Activity is best quantified by measuring absolute chromospheric fluxes at the stellar surface (Catalano 1979, Linsky et al. 1979). By looking for correlations between fluxes and stellar parameters, dependence of activity has been proposed on stellar rotational velocity (e.g. Strassmeier et al. 1993), effective temperature (e.g. Rutten 1987), mass and evolutionary status (Pasquini and Brocato 1992). Acoustic heating mechanisms have been invoked, e.g. by Ulmschnider et al. (1996), while magnetic heating is preferred by others (e.g. Strassmeier et al. 1993, Pasquini and Brocato 1992); some authors find evidence for the presence of both, acoustic and magnetic mechanisms (Rutten 1987).

The attempts to parameterize activity with stellar quantities suffer of a fundamental observational bias: being based on field stars, several of the stellar parameters suffer by large (and difficult to quantify) uncertainties. These problems can be overtaken by observing stars in clusters.

2.1. M67

M67 is an extremely interesting cluster: it has metallicity and age comparable to the Sun, it is rich in stars and well studied for membership and photometry. Dupree et al. (1998) have obtained Ca II H and K high resolution observations for 15 giants in M67, from the brightest RGB stars to the clump giants, at an absolute magnitude M_v=2. Absolute surface fluxes were obtained from the spectrophotometry of Gunn and Stryker (1983) and the photospheric contribution was computed by constructing new, detailed line profiles. The derived chromospheric fluxes are shown in Figure 1 (open squares) and refer to the K line only.

From Figure 1 two main points emerge:

1. The correlation between activity and T_{eff} is very clear. In this coeval (and single mass) sample, chromospheric activity decreases with stellar effective temperature, with little scatter around the observed relationship. Is this decrease in activity driven by the evolution of the stellar angular momentum ? At the moment a firm answer to this question cannot be given, but the observed trend may not correspond to what expected by the rigid body evolution predictions (Rutten and Pylyser 1989).
2. Among the M67 giants, no difference in activity exists between clump stars and RGB stars. This implies that activity does not depend in this cluster on the stellar internal structure.

In Figure 2 the M67 data are compared with equivalent data from several clusters, taken from Beasley and Cram (1993) and Pasquini et al. (1998). Note that in the fluxes given in this Figure, the photospheric contribution has not been subtracted. The sampled clusters span from young, massive clusters NGC6067 and NGC2516($\sim$4$M_\odot$), through the Hyades and Praesepe (2 $M_\odot$), IC 4651 (1.4 $M_\odot$) and M67 (1.2 $M_\odot$), to two stars

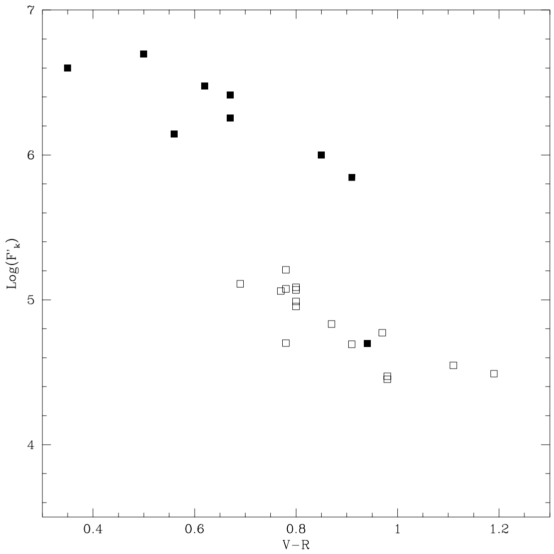

Fig. 1. Chromospheric fluxes vs. V-R for the M67 giants (open squares) and for the X-ray selected candidates (filled squares)

of the GC NGC6752 (0.8 $M_\odot$). Even if not all ranges of masses, ages and effective temperatures are evenly covered, several conclusions can be driven from Figure 2:

The Hyades and Praesepe clump giants, which have similar masses and effective temperatures, have the same level of activity. This is in agreement with Randich and Schmitt (1995) who found similar X-ray luminosities for the giants of the two clusters. Note also that the Ca II fluxes of the Hyades giants differ by up to 0.4 dex. Since this difference is likely caused by long term activity cycles, it sets a lower limit to the intrinsic spread that should be expected when observing similar giants belonging to a cluster.

When only stars within a limited range of masses (0.8-2 $M_\odot$) are considered, all follow the same relationship within the cosmic spread, and effective temperature seem to be the driving parameter.

The observed spread increases when stars belonging to the younger (more massive) clusters are considered. Even if only a few massive stars are present in Figure 2, they tend to be more active than the lower mass stars with similar colors. It is worth noticing that the results of Figure 2 are consistent with the shift expected by applying the log(F'$_k$)-Log(M) relationship found by Pasquini and Brocato (1992).

Finally, as pointed out by Dupree et al. (1990, 1994), the two GC giants do NOT show a lower level of activity with respect to the Pop I stars.

M67 has also been observed in soft X-rays by ROSAT, and these observations have revealed several coronal sources (Belloni, these proceedings). Out of the 28 ROSAT sources, 11 have been identified with stars (mostly binaries) belonging to the cluster.

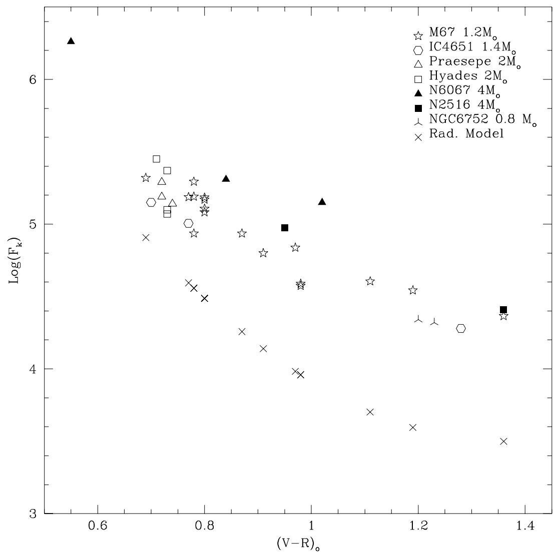

Fig. 2. Chromospheric K line fluxes vs. (V-R)$_o$ for giants in clusters of different masses

For some of them, high resolution spectroscopy and determination of the chromospheric fluxes in the Ca II lines were possible (Pasquini and Belloni 1998) and chromospheric fluxes for the X-ray candidates are shown in Figure 1 as filled symbols.

Among the X-Ray selected stars, the majority shows very high Ca II fluxes, $\sim$10 times higher than 'normal' stars with the same colors. Only one candidate (S364, Sanders 1977) has an activity level which is comparable to the 'normal' giants, and in fact, Pasquini and Belloni (1998) classify this star only as a possible ROSAT counterpart.

Among the ROSAT stars, while X-ray luminosities and chromospheric fluxes span over less than one order of magnitude, stellar luminosities span over 4 magnitudes. In Figure 3a, the ratio between X-ray and Ca II fluxes: F_x / F'_k is shown as a function of stellar color (V-R). In Figure 3b, the same ratio is shown vs. the stellar magnitudes. Evolved and main sequence stars occupy different regions in this diagram, with dwarfs having much higher coronal to Ca II fluxes than the giants. This may imply that dwarfs and giants have different efficiencies in transforming chromospheric heating into coronal heating, for instance, due to the presence of different coronal structures. On the other hand, one has to remember that only a fraction of the chromospheric flux is emitted in the Ca II lines, with the rest emitted in other (Balmer, Mg II) lines and in the continuum. An alternative interpretation could therefore be that main sequence and evolved stars have a different distribution of the chromospheric losses among the various chromospheric indicators.

Finally, among the ROSAT counterparts in M67, two objects deserve a special mention: they have a unique location in the cluster color-magnitude diagram, just below the

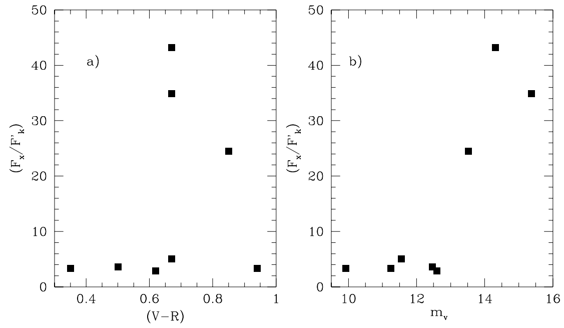

Fig. 3. Ratio of the Ca II K line fluxes to X-ray fluxes as a function of (V-R color) and of the stellar visual magnitude

subgiant branch, in a position which cannot be reproduced by the simple combination of single clusters stars. These two stars have likely experimented mass transfer and they may represent a new class of very active systems.

3. GC: Mass Losses and Chromosphere

The presence of considerable mass losses during the RGB phase of GC stars is primarily required by stellar evolution theories in order to explain the morphology of GC Horizontal Branches (Renzini 1977).

This prediction was shortly followed by several surveys carried out at intermediate and high resolution, mostly in the Hα line. Observations in many GC stars (Cacciari and Freeman 1983) found Hα in emission in 30% of the giants more luminous than Log(L/L$_\odot$)=2.7. They argued that the fraction of Hα emission stars depends on the cluster metallicity. Gratton et al. (1984) obtained similar results, but found a higher percentage of emission stars, likely thanks to the higher spectral resolution used. A dependence of the mass loss rates on the cluster HB morphology (clusters with Red HB having less emission) or on stellar microturbolence was proposed. Both groups found evidence for variability of the Hα line, with timescales as short as a few days. Interpreting the Hα emission as due to the presence of an expanding envelope, the computed mass losses were of the order 10^{-8} solar mass/year, in good agreement with what needed from theory.

This interpretation was challenged by Dupree et al. (1984) who showed that Hα emission can naturally be produced by the presence of a chromosphere. Also, the observed Hα asymmetries could not always be explained with an expanding envelope model.

The presence of chromospheres was confirmed by Dupree et al. (1990, 1994), who found evidence for Mg II emission in Pop II field giants and in the two brightest stars of NGC6752.

To disentangle between these interpretations, high resolution spectroscopy is required, in order to allow a careful analysis of line shifts and asymmetries. Lyons et a. (1996) have obtained high resolution spectra in the Na D and Hα lines for $\sim$65 stars belonging to several GC, finding significative shifts and line asymmetries up to a few Km/sec (lower than the escape velocity), in stars brighter than Log(L/L$_{\odot}$) $\sim$2.5. Dupree et al. (1994) measured shifts in the Mg II lines up to 150 Km/sec; this finding, when confirmed by a larger body of observations, will clearly indicate the presence of substantial mass losses.

It seems therefore that both chromospheres and massive winds can be present in the atmospheres of GC bright giants. It is also clear that different conclusions could be reached depending on the line diagnostic used, if a proper model of the chromosphere is not performed. The variability observed in Hα would indicate, for instance, that this line likely forms in a dynamically variable region.

For this reason, Cacciari et al. (1998), started a long term program aiming at observing GC giants in many lines, including Ca II, Na D, Balmer lines, with the aim of obtaining a detailed modeling of their chromospheres. Ca II K line spectra of 4 luminous giants in NGC 6752 are shown in Figure 4. These spectra confirm the presence of conspicuous chromospheres in these stars, but they also show that the Ca II line does not present a smooth magnitude - line core asymmetry trend observed, for instance, in the M67 giants by Dupree et al. (1998). The comparison of Ca II spectra taken at different epochs will reveal if variability is present in these lines, possibly confirming the hypothesis that also the Ca II H and K lines in GC giants are formed in a dynamically active region (Dupree et al. 1994).

4. New Instruments at ESO

Much observational work still needs to be done in old clusters in order to understand the nature of chromospheric activity, to quantify mass losses. Very little is known about the dependence of activity on metallicity, mass and age. To proper cover this space, observations should develop into two different, complementary lines: multi object spectroscopy (to acquire statistically significant samples) and large spectral coverage (to acquire many simultaneous diagnostics). Particularly relevant to this context, two instruments will soon be available at ESO, which will represent a significant advance:

4.1. FEROS at the ESO 1.52m at the La Silla Observatory (available for users: end 1998, Kaufer et al. 1997)

In the previous sections clearly emerged the importance of having an instrument capable to provide high spectral resolution *and* broad simultaneous spectral coverage. The new Fibre Extended Range Optical Spectrograph (FEROS) at the ESO 1.52m will be able

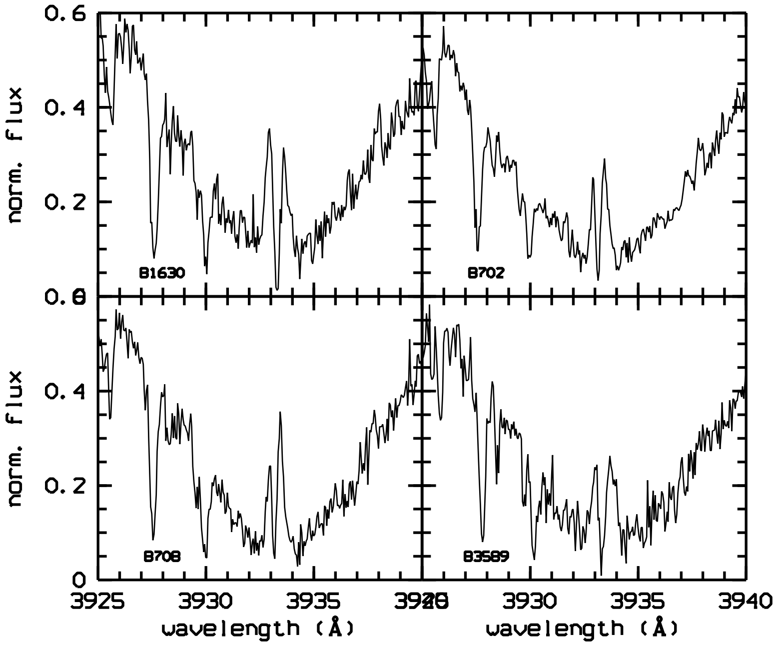

Fig. 4. Ca II K line spectra of 4 giants belonging to the GC NGC 6752

to provide these characteristics, together with an high overall efficiency. The resolving power will be R∼50000, and a simultaneous coverage of the 370-860 nm range is ensured. It will be possible to switch in a few minutes between the low resolution B&Ch spectrograph (e.g. to obtain spectrophotometry) to the FEROS spectrograph. Finally, thanks to its fixed format, FEROS will be equipped with full on-line data reduction. Being FEROS permanently mounted, it will be ideal for those programs requiring long term studies, as required to investigate chromospheric variability and its timescales.

4.2. FUEGOS at the Unit 2 of the VLT Observatory (available to the users: 2001, Felenbok et al. 1994)

This is a unique facility among the 8 M telescope, coupling high resolution (R∼17000) with multi object capabilities (∼80 objects) over a large (25 arcmin diameter) field.

Although only one single order will be simultaneously covered, its multiplex capabilities over a large field, coupled with high efficiency and an 8m telescope, will make of Fuegos the instrument which can really make the break-through in clusters spectroscopy. It will be possible to study chromospheric activity not only in giants, but for the first time also in main sequence stars in a large number of open clusters and in the nearest globulars.

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