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CHROMOSPHERIC ACTIVITY, STELLAR WINDS AND RED STRAGGLERS

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RESUMEN

Presentamos varias estrellas de Secuencia Principal, de tipos tardíos, cuya intensa actividad cromosférica implicaría edades significativamente menores que las derivadas de su cinemática. Discutimos varios procesos que pueden explicar esta inconsistencia y concluimos que la explicación más probable está en el rejuvenecimiento de la componente primaria de un sistema binario cercano ($P < 5$ días), ya sea por el "spin-up" inducido por la pérdida de momento angular orbital a través de sus vientos magnetizados, o por la final coalescencia del par. Proponemos, por analogía con el fenómeno "blue straggler", llamar a estos objetos "red stragglers", ya que ellos escapan a sus posiciones esperadas en el espacio de velocidades.

ABSTRACT

We present a number of late type main-sequence stars whose strong chromospheric activity would imply ages significantly smaller than those given by their kinematics. We discuss processes which may explain this inconsistency, and conclude that the most likely explanation is the rejuvenation of the primary component of a close binary ($P < 5$ days), either by the spin-up induced by the loss of orbital angular momentum through their magnetized winds, or by the final coalescence of the close pair. By analogy with the blue straggler phenomenon we propose to call the coalesced objects "red stragglers", since they straggle out of their expected position in velocity space.

Key words: **DUST, EXTINCTION — LINE: PROFILES — STARS: MASS LOSS — STARS: PRE-MAIN-SEQUENCE**

1. INTRODUCTION

The phenomenon of colliding winds has been extensively studied and documented since the pioneer work of Jorge Sahade in the late fifties'. Much of the work has dealt with winds in massive early-type stars where radiation pressure is the driving agent of the winds. At the other end of the H-R diagram low mass G, K, and M stars also have substantial winds, but in this case they are driven by the magnetic activity related to convection and rotation.

A striking example of colliding winds in pre-stellar nebulae are the Herbig-Haro or HH objects, small compact emission nodules that were discovered independently by Herbig (1951) and Haro (1952). Both authors noted their peculiar spectra, rich in low and high excitation and ionization lines, as well as the absence of any apparent source of excitation in their vicinity. It took more than 20 years until the mystery of the HH objects began to be unveiled. Schwartz (1975) opened the way by pointing out that the HH spectra resemble the ones calculated by Cox (1972) for shock waves. Herbig & Jones (1982) found that some HH objects show remarkably high proper motions corresponding to tangential velocities of up to 300 km s^{-1}.

Much work has been done to model the type of flows that lead to shocks capable of explaining the HH objects. The classical studies on this subject (Cantó et al. 1981, and references therein) assume a star with a strong isotropic wind immersed in an interstellar disk, creating two symmetric ovoid cavities where the stellar wind shocks and slides along their surfaces. These flows converge at the tips of the cavities where the gas collides with itself producing a shock. With reasonable values for the wind velocity and density the HH morphologies and spectra can be obtained. Moreover, the velocities of the winds and of the shocks are found to be consistent with the observed transverse velocities in HH objects (Jones & Herbig 1982). References to many recent results on this topic can be found in Lizano & Torrelles (1995).

Among the low mass stellar objects, colliding winds should be present in close binaries with chromospheric activity entailing significant winds. Low mass stars (M $<$ 1 $M_\odot$) have convection zones all the way from their pre-main-sequence contraction phase throughout their main-sequence lives. Convection in such stars is present for billions of years. Rotation is a different matter: stellar winds and flares carry away substantial amounts of angular momentum through the magnetic coupling of the ejected material, thus slowing down the rotation of the star. Skumanich (1972) found that the rotational velocity of single stars decays with time as $t^{-1/2}$.

It has been known for many years that some stars exhibit conflicting ages according to different dating methods. The term "blue stragglers" was coined by Burbidge & Sandage (1958) to describe such stars, first found in globular clusters.

At the opposite end of the color-magnitude diagram, other stars have begun to be recognized as having conflicting ages. These new objects exhibit inconsistent ages as determined by their chromospheric activity (indicating youth) and their kinematics or chemical composition (corresponding to a much older disk or even halo population). In fact, in a UV plane these new objects scatter or straggle significantly beyond the distribution of the velocities of the majority of objects of their class.

Our interest in this subject arose while investigating the kinematics of UV Ceti stars (Poveda, Allen, & Herrera 1995, 1996a, hereinafter PAH). We found that the great majority (86) of the well established UV Ceti stars in the solar neighborhood have a velocity distribution similar to that of the F5 V stars, indicating a mean age of 3–4 Gy, while a small group of them (7) strongly deviates from this majority, suggesting ages comparable to those of the oldest disk or even halo objects.

2. DEFINITION AND KINEMATICAL CHARACTERIZATION OF RED STRAGGLERS

Our purpose is to identify stars whose significant chromospheric activity would lead to the assignment of young ages to them, but whose kinematics or chemical composition are those of old objects, of ages comparable to those of the oldest disk or halo stars. As a starting point, we will consider as young objects stars with strong chromospheric activity, as revealed by at least one of the following indicators:

1. Strong calcium H and K emission.
2. Hα emission.
3. Flare activity.
4. BY Draconis syndrome.

The kinematic properties of the four groups of chromospherically active, young stars indicated by the above mentioned criteria, are all consistent, within the expected uncertainties. We find for them an average velocity dispersion σ_T of about 29 km s^{-1}. This velocity dispersion is very similar to the value found for 24 F4 V and F5 V stars from the catalogue of Gliese & Jahreiss (1991), namely $\sigma_T = 28$ km s^{-1} (Poveda et al. 1995, 1996a). The main sequence lifetime for these stars (F4 V) is approximately 5 Gy (Meynet et al. 1990). Under the reasonable assumption of a constant star formation rate, we estimate that the mean age for the chromospherically active stars listed above is about 2.5 Gy, which means that they are young compared to the age of the Galaxy.

Based on these results, we seek now to define a volume in velocity space —the volume of youth— outside of which no young objects (or very few of them) are expected to exist. Hence, the great majority of the stars found outside that volume can be taken to be old. For this purpose we consider the velocity dispersions of the most reliable group of UV Ceti stars in the solar neighborhood, namely those with absolute visual magnitudes brighter than 13 and contained within a sphere of 13 pc of radius. This group was found to have velocity dispersions σ (U,V,W) = (23, 10, 11) km s^{-1}. In a Gaussian population characterized by such dispersions, only 1% of the members are expected to lie beyond 2.57 σ. This corresponds to velocities $|U| = 59$ km s^{-1}, $|V| = 26$ km s^{-1}, and $|W| = 28$ km s^{-1}. We will adopt as round values for our limits $|U| > 60$ km s^{-1}, $|V| > 30$ km s^{-1} and $|W| > 25$ km s^{-1}, taken with respect to the local standard of rest. These are plausible values to identify a population of older objects, because we recall that in their lifetime the galactic disk objects, which are born with space velocity dispersions of about 10 km s^{-1}, will be "heated up" by encounters to achieve dispersions σ (U, V, W) of about (60,30,25) km s^{-1} (Wielen 1977). We thus infer that the majority of objects with velocities surpassing these limits will in fact be old, of ages comparable with those of the oldest objects of the galactic disk. The possible presence of a few (of the order of 1 or 2) young objects among the group so selected will be of little importance for our present purposes. Hence, we define as red stragglers those stars which exhibit any one of the indicators of youth (1) to (4) listed above, and which either reside outside the velocity space volume of youth and/or have photometric or spectroscopic indicators of old age.

3. A LIST OF RED STRAGGLERS

Table 1 contains a list of old, chromospherically active, single stars selected according to the criteria with which we define a red straggler. Details about the compilation of Table 1 can be found in Poveda et al. (1996b).

TABLE 1

OLD, SINGLE, CHROMOSPHERICALLY ACTIVE STARS

Star[a]	Age	Activity	U km s^{-1}	V km s^{-1}	W km s^{-1}	Reference[b]	Remarks[c]
Gl 22 AB	K	Flare	−59	−32	−11	1	...
Gl 83.1	K	Flare	+23	−40	+12	1	...
Gl 166C	K	Flare	+106	+1	−29	1	...
Gl 406	K	Flare	−17	−32	−12	1	...
Gl 412 B	K	Flare	−123	+6	+19	1	a
Gl 424	K	Flare	−128	+2	+5	1	a
Gl 451 B	K	Flare	+274	−137	+1	1	a
GJ 1116AB	K	Flare	+19	+25	−30	1	...
Gl 431	K	Flare	−47	+72	−18	1	...
Gl 725 A	K	Flare	−15	+0	+33	1	...
Gl 725 B	K	Flare	−15	+2	+34	1	b
Gl 752 B	K	Flare	+62	+6	+2	1	...
Gl 815 B	K	Flare	+9	−23	−36	1	c
Gl 825	K	Flare	+72	−7	+30	1	...
Gl 852 A	K	Flare	+54	+33	−26	1	...
Gl 866 AB	K	Flare	−60	+11	+48	1	...
Gl 899	K	Flare	+100	+3	+18	1	...
Gl 908	K	Flare	+0	−56	+48	1	...
Gl 641	K	H&K str.	+93	−96	+17	2	...
Gl 1	K	Hα em	−69	−89	−28	3	...
Gl 176	K	Hα em	−14	−45	−5	3	...
Gl 611.3	K	Hα em	−50	−33	+27	3	...
Gl 802	K	Hα em	−131	−20	+29	3	...
Gl 905	K	Hα em	+42	−62	+7	3	...
Gl 53.1 A	K	H&K = 2	+14	−17	−34	4	...
Gl 69	K	H&K = 2	+54	−16	−35	4	...
Gl 273.1	K	H&K = 2	+19	+23	+25	4	...
Gl 380	K	H&K = 2	0	−8	−28	4	...
Gl 546	K	H&K = 2	−14	−41	−13	4	...
GJ 1113	K	H&K = 2	−45	−8	+30	4	...
G 64–34	M	Flare	+61	−45	+55	5	c
Gl 812 A	M	Flare	−50	−25	−22	6	c
Gl 15 B	M	Flare	−38	+0	+4	6	a, c

[a] Gl, GJ and G numbers are from Gliese (1969); Gliese & Jahreiss (1991), and Giclas et al. (1961-1968), respectively.

[b] (1) Poveda, Allen, & Herrera 1996a; (2) Soderblom 1990; (3) Joy & Abt 1974; (4) Wilson & Woolley 1970; (5) Schuster 1989; (6) Stauffer & Hartmann 1986.

[c] (a) Subdwarf, (b) radial velocity probably variable, (c) low metallicity.

TABLE 2

OLD, CHROMOSPHERICALLY ACTIVE, LOW-MASS, CLOSE BINARIES

Star	Age	Activity	U km s^{-1}	V km s^{-1}	W km s^{-1}	Reference[a]	Period days	Remarks[b]
Gl 630.1 A	K	Flare	−94	−119	−27	1	1.27	...
Gl 725 B	K	Flare	-15	+2	+34	1	?	...
Gl 781	K,M	Flare	+116	+0	+49	1	< 0.9	subdwarf
Gl 815 A	K	Flare	−9	−23	−36	1	3.28	...
HD 89499	M	H&K em	...	...	...	2	5.57	...
BD −0 4234	K	H em	−124	−67	−2	3	3.76	...
Gl 103	K	Flare	+15	−18	−26	1	1.56	...
HD 80715	K	H em	−13	−39	−21	3	3.80	...

[a] (1) Poveda, Allen, & Herrera 1996a; (2) Pasquini & Lindgren 1994; (3) Strassmeier et al. 1988.
[b] Subdwarf.

Table 2 contains stars that satisfy the criteria for being red stragglers,and which are low mass binaries with periods of less than about 6 days. As will be discussed later, these stars will evolve first into contact binaries, and then coalesce into a single star, during a timescale short compared to the age of the galactic disk. Hence, they constitute the most likely progenitors of objects like those listed in Table 1.

The first column of Tables 1 and 2 contains the stellar identification. A "K" in the 2nd column (labelled "Age") means that the star was selected as being old because of its kinematics, placing it outside the volume of youth as defined above. An "M" in the same column means that the star was considered to be old because of its metallicity. The third column contains the criterion used to select stars with significant chromospheric activity. "Flare" means that it has confirmed flare activity; "H&K" means that it has either strong calcium H and K emission or a Wilson-Wooley index equal or larger than 2. The next columns (4th, 5th and 6th) contain the space velocity components with respect to the local standard of rest. 7th column lists the bibliographic reference used for the stellar data. Finally, the last column ("Remarks") includes miscellaneous information about the objects in Table 1 and the binary period (if known) in Table 2.

4. DISCUSSION AND CONCLUSIONS

There is ample and convincing evidence (Pasquini & Lindgren 1994, Strassmeier et al. 1988) that in close binaries (with periods of less than 10 days) tidal locking forces the synchronization of the rotation and orbital periods. When at least one of the components of the close binary is a late-type star (K or M) with deep convection zone, and such that the Rossby number R is less than about 2/3, intense chromospheric activity will be maintained indefinitely. Clear examples of this process can be found in Pasquini & Lindgren (1994), who show that chromospheric activity in old binaries sets in for periods shorter than about 10 days.

The loss of angular momentum forces the orbital period, and hence the separation of such pairs, to be steadily decreasing, producing first a low mass contact binary and eventually the coalescence of both components.

The process by which a short period detached binary becomes a contact binary and then a coalesced single star has been clearly recognized in the case of intermediate mass stars. W Ursae Majoris stars become contact binaries and then coalesce into blue stragglers (Guinan & Bradstreet 1988). For lower mass stars no such clear evidence has been recognized.

Stepien (1995) has calculated the period evolution of close binaries under the assumptions of (a) tidal synchronization and (b) angular momentum loss according to the Skumanich $t^{-1/2}$ law for single stars (Skumanich 1972). He shows that a low mass binary consisting of two 0.6 $M_{\odot}$ components with an initial orbital period of one day reaches contact in less than 1 Gy, while a binary with a two-day period does so in 2–5 Gy; but it takes 6 Gy for the same binary to reach contact if its initial period is 3.4 days, and 12 Gy if it is 5 days. For smaller masses the time to coalescence is shorter. The times calculated by Stepien should be corrected upwards because they are based on Skumanich's law, which is valid for single stars only; in the case of very close binaries the collision of their winds will generate a shock located between the two components that will shorten the radius of co-rotation, thus reducing the rate of angular momentum loss; a crude estimate, assuming that about one half of each wind is inhibited, yields an increase of about 1 Gy for the time to coalescence.

Therefore, we may conclude that low mass binaries (M1 = M2 = 0.6 $M_{\odot}$) with initial periods shorter than about 6 days, and coeval with the formation of the galactic disk have already coalesced. They would be observable now as single, chromospherically active, and kinematically old stars. Stars Gl 412B, Gl 424, and Gl 451B (all having unequivocal flare activity, while showing evidence of metal deficiency and being extremely high velocity objects) are particularly good examples of this evolutionary process. Other objects in Table 1, though not as extreme, are additional examples. The binaries listed in Table 2, such as Gl 630.1A (with a period of 1.27 days), and BD −00 4234 (with a period of 3.76 days) are good examples of likely progenitors of the red stragglers listed in Table 1.

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