EVOLUTIONARY POSSIBILITIES AND IMPOSSIBILITIES FOR SOLAR TYPE CONTACT BINARIES IN NGC 188.

Frans VAN 'T VEER
Institut d'Astrophysique de Paris
98 bis, boulevard Arago - FRANCE.

Abstract

We give a great number of arguments for the hypothesis that several epochs of star formation have taken place at different times in the old galactic cluster NGC 188.
From the last burst of star formation in this cluster, not more than a few times 10^8 years ago, 4 contact binaries are still now visible as W UMa stars. With the aid of a simplified probability calculation we argue that these 4 contact binaries are physically related and that the alignment of the orbital axes is not accidental.

Introduction

We consider as W UMa binaries all late type (later than F5) contact binaries which show light variations due to tidal distortion and/or eclipses. Supposing a, (not generally admitted) random orientation of the orbital axes they represent about 25 to 30% of the total number of late type contact binaries. It has been recognized for a long time that they outnumber all others types of close and wide binaries together, and their importance for the evolution of small mass stars was rapidly understood (Shapley, 1948; Struve, 1950; Strömgren, 1952). Also their possible relationship with planetary systems was sometimes suggested (Struve, 1950; Van 't Veer, 1975.
One can also find in the literature on this subject a certain number of suggestions concerning their alleged progenitors and descendants. Most people believe indeed that their appearance is a stage of limited duration in a cycle of stellar phenomena. The problem however is to identify the other stages of the cycle and the lifetime of the W UMa stage. The estimation of their lifetime varies considerably from one author to the other (see for example the discussion in Van 't Veer, 1976) but we now possess modern observations in UV and X-ray wavelengths. These are in

Z. Kopal and J. Rahe (eds.), Binary and Multiple Stars as Tracers of Stellar Evolution, 279–287.

favour of a model with high angular momentum loss (Van 't Veer, 1979, Vilhu and Rahunen, 1980) and a resulting short lifetime not exceeding 10^8 years as originally advocated by Van 't Veer (1975). Nevertheless the file concerning the question of age is certainly not closed. We think however that the conclusion, now and then found in the literature, that contact binaries should be evolved, does not seem tenable.
The simple reason for this was formulated recently (Van t Veer, 1980) by the simple question : if all contact binaries are evolved, what do they look like when they are young or simply on the main sequence? We therefore believe that all studies reporting higher than main sequence radii for contact binaries do not demonstrate that these objects are evolved, but that on the contrary most of them are still contracting towards the main sequence.
All these facts make the W UMa stars one of the most fascinating groups of close double stars. We now shall discuss the puzzling presence of 4 of them in the old galactic cluster NGC 188.

The problem

The whole question may be formulated as follows : if these 4 W UMa stars discovered by Hoffmeister (1964) in NGC 188, are of the same age as the cluster (5×10^9 years deduced from its colour - magnitude diagram by Demarque, 1979) we are confronted with the problem of how to keep them alive after such a long time.
In the following pages we shall try to analyze what is possible and what is not possible in this domain. Since however we do not pretend to detect the true possibilities of nature we shall limit ourselves to such notions as probable, less probable, improbable and highly improbable. These man made probabilities will be the basis of our conclusions formulated at the end of this paper.

The definitions of age and life time

This question was recently treated by us (Van 't Veer, 1980) in response to a note on young clusters (Ruciński, 1980) and it is perhaps good to give some clear and succint definitions concerning the ages and lifetimes of contact binaries :

Contact age = t = time elapsed since contact, or first contact if we suppose that the contact may be broken temporarily one or more times.
Contact lifetime = t_{max} = lifetime in the contact stage of evolution.
Pre-contact lifetime = τ = total lifetime of all evolutionary stages preceding contact.
Stellar age = $t + \tau$
Stellar lifetime = $t_{max} + \tau$

Every body will agree with the following statement :
The age of a contact binary cannot exceed its maximum possible stellar lifetime.

https://doi.org/10.1017/S0252921100100600 Published online by Cambridge University Press

NGC 188 -

We now return to NGC 188. It is the only old galactic cluster which seems to possess more than one contact binary. This fact is important and it makes the difference with clusters, like M 67, which only have one contact binary. In such cases its presence may be more easily explained by the coïncidence of a fore - or background object. For NGC 188 this explanation is highly improbable : the presence of 4 W UMa stars sitting at not more than $0.^{m}5$ distance from the main sequence would suppose a local space density of these objects in the neighbourhood of the cluster of more than 20 times the mean space density.
This hypothesis would be a highly improbable solution and as far as we know everybody believes that the 4 W UMa stars of NGC 188 are members of the cluster.

How many contact binaries - The first conflict.

We will continue with the hypothesis of membership and try to find out first how many contact binaries must be present in the cluster. This problem may also be treated statistically. We observe 4 W UMa stars, the amplitudes of their light curves lie in the interval $\Delta m = 0.^{m}45 - 0.^{m}8$, the B-V colour varies from $0.^{m}8 - 0.^{m}9$. If we reasonably admit that they all have a mass ratio q = 0.3 - 0.6 and a surface temperature of 5000 ± 500°K we may calculate the range of inclinations i which is necessary to produce the observed range of amplitude. Table 1 reproduces the result of our calculation. We see that the probability p for a contact binary to be a W UMa star with a light curve exhibiting an amplitude between $0.^{m}45$ and $0.^{m}80$ (group I) is $p = \Delta i/90 = 0.17$ in the case of a random orientation of the axes. The probability is p = 0.28 for an amplitude between 0.15 and 0.45 (group II) which should also be detectable in a well studied cluster like NGC 188. The probability becomes p = 0.55 when we consider amplitudes smaller than $\Delta m = 0.15$ (group III) that means difficult to detect.
So we immediately see the surprising observational fact that 4 W UMa stars are present in group I and none in group II. Group III will contain a number of contact binaries which is unknown because of their undetectability. With these observational facts and probability results in mind we may now derive some interesting statistical conclusions concerning the answer to the following question : What is the most probable total number of contact binaries present in NGC 188, so that 4 of them have orbital inclinations between 75 and 90° as observed? The answer requires some statistical preparation. We imagine first the cluster without contact binaries. We then throw a certain number (n) of contact binaries of the observed colour range into the cluster in a random way and finally examine the probabiliy to find the really observed situation.
From binomial theory we can derive that the probability b to find k contact binaries in I, l in II and m in III is :

Table 1 -

Amplitude of life curve ΔM_V	Corresponding mean inclination i	Range of inclination Δi	Group	Probability of being member of group I, II or III $\Delta i/90$
0.80	90			
		15	I	$P_I = 0.17$
0.45	75			
		25	II	$P_{II} = 0.28$
0.15	50			
		50	III	$P_{III} = 0.55$
0	0			

Table 2 -

n	q_n
4	0.00084 (0.17)
15	0.138
20	0.203
23	0.212
24	0.213
25	0.212
30	0.183
35	0.142

https://doi.org/10.1017/S0252921100100600 Published online by Cambridge University Press

$$b(k,l,m)=\frac{(k+l+m)!}{k!\,l!\,m!}\,p_I^{\,k}\,p_{II}^{\,l}\,p_{III}^{\,m}$$

the first factor at the right-hand side being the total number of possibilities to find k, l, and m contact binaries in I, II and III respectiveley. Evidently

$$\sum_n b(k,l,m) = 1$$

when counted over all possible combinations k+l+m = n.
In the case of NGC 188 we know that k = 4 and it is now easy to calculate the possibilities for different values of n. Some of the results can be seen in table 2 which gives the probability q_n that 4 W UMa stars may be found in the group I when we randomly throw n contact binaries in the cluster. It is clear that we reasonably need between 20 and 30 contact binaries. About 1/3 of them would have, at least statistically, light curves with amplitudes between $0.^m15$ and $0.^m45$ (group II) and hence would be also detectable as W UMa stars.
If we now admit the most probable solution of table 2 we are confronted with 2 unsolvable problems which we will call the first conflict :
1. There are about 20 unidentified contact binaries (thus seen as normal main sequence stars) in the range $0.^m8 < B-V < 0.^m9$ that means more than half the number of observed main sequence stars in that range (Sandage, 1961; Mc Clure and Twarog, 1977);
2. among these 20 stars there should be 6 or 7 W UMa stars with an amplitude $0.^m15 < \Delta m < 0.^m45$. These detectable contact binaries have never been seen.
These results make us believe that NGC 188 does not possess 20 or 30 contact binaries. There are not more than 4 contact binaries which, perhaps thanks to a statistical accident, have about the same orientation in space. One can also think that the alignment of the axes is the result of some physical cause. In that case, the probability to find 4 W UMa stars with only 4 contact binaries is much greater (0.17). In our conclusions we will return to this question.

How old are they? - The second conflict.

The next problem is at least as difficult to solve as the preceding one. From our definitions of ages and the results of laborious work, cited here above, on the colour-magnitude diagram of NGC 188, we may infer that we need stellar ages for our contact binaries which are not far from 5 x 10^9 years. In that case we evidently suppose coeval formation of all stars of the group. We further know with a high probability that the contact lifetime $t_{max} < 10^8$ years so it follows that a pre-contact lifetime of 4.9×10^9 years is necessary. Two different pre-contact stages may be envisaged :
1 - Single star progenitor (before splitting),
2 - Binary progenitor (detached or semi-detached).
Splitting of a single star may only be conceived during evolutionary stages of rapid rotation accompanied by sufficient contraction. These are only found during pre-main sequence evolution when the star is very

young. The second process may have better chances. Detached and semi-detached binaries, which have been formed by the fragmentation process may evolve into contact binaries. For that it is necessary, as was pointed out by Huang (1966) and Mestel (1968) that the combined action of angular momentum loss and tidal coupling between spin and orbital momentum brings about a slow approach during the time τ estimated above. In principle one can imagine a loose interaction so that it is possible to bring together two late type stars in about 5×10^9 years. In most cases however the interaction is much stronger and will only take some 10^8 years to achieve the approach (Van 't Veer, 1979). Needless to say that it is highly improbable that this mechanism will produce 24 or even 4 contact binaries 5×10^9 years after the birth of a cluster, and no other sorts of late type close binaries.

Summarizing we can say that it is highly improbable to explain the number or the age, let alone both, in the classical way by coeval formation of non aligned contact binaries.

Hence our conclusion is that these 4 contact binaries were formed not only much later than the main part of the cluster but also with a non-random distribution of the orbital axes. This somewhat crude statement is in agreement with the observational fact that no binaries are observed in the old globular clusters (Liller, 1979). The real or observed absence of close binaries in globular clusters may be due to a lower rate of formation (angular momentum, viscosity) but also to an increased disappearance due to:

1 - Angular momentum loss by magnetic activity,
2 - disruption by close encounters,
3 - disruption by explosion of one of the components,
4 - invisibility due to death of one of the components.

Coeval or non-coeval star formation.

We give the following formulation to the problem: is it reasonable to suppose that star formation in a cluster may take place at different times, and even until rather recently in the case of old galactic clusters? The idea is not completely new. For example for the young Pleiades we know that age determination from massive (turn off) and light stars (turn on) differ from 7×10^7 to 2.2×10^8y (Stauffer, 1980) indicating a non-coeval formation of these stars. In a spectroscopic study of the galactic cluster M67(4×10^9y.) Barry et al.(1981) concluded that several bursts of star formation should have taken place at different epochs. They used the H and K line emission as a criterion of age. There are still other examples but we shall return to NGC 188 and have a look to the abundant literature concerning this cluster.

We first see that the determination of the age raises some problems. From the diagrams with isochrones for M67 and NGC 188 published by Sandage and Eggen (1969) and Twarog (1978) we see that it is difficult to give an unambiguous age to these clusters even when we limit ourselves to stars in the neigbourhood of the turn off. The reason for this is that the giant branch intersects different isochrones. Furthermore the absolute magnitude range for the NGC 188 giants later than G8 is about 3^m.

This corresponds to a factor of 10 in luminosity and indicates that late type giants up to $3m_{\odot}$ are present in the cluster. These G8 giants cannot be older than a few times 10^8 years. For statistical reasons it is improbable that these stars may be eliminated as foreground stars. We shall not say more about this question. These and other problems were studied by Eggen and Sandage (1969) who already suggested that two epochs of star formation could have existed.

The next point is the presence of blue stragglers in the cluster. They are characterized by a position in the colour-magnitude diagram located on the blue side extrapolation of the main sequence.

Different explanations for the origin of blue stragglers in NGC 188 and many other old clusters have been put forward.

Among these explanations we find :

1 - binaries with special mass exchange conditions, (McCrea, 1964; Van den Heuvel, 1968).

2 - single stars with quasi-homogeneous evolution and extensive internal mixing, (Wheeler, 1979).

3 - or simply normal main sequence stars which are formed later (Hintzen et al.,1974).

Without discrediting the often ingeneous processes invented in order to support the first and second explanations, we believe that the third hypothesis is the more natural. It supposes that a burst of star formation has taken place at an epoch less than 10^9 years ago. This epoch explains the presence of stars with $m = 2m_{\odot}$ on the main sequence.

Another effect may be considered as important in this context. There is a considerable scatter in the main sequence for stars with masses $m < m_{\odot}$. This scatter is much greater than the one observed for younger clusters like the Hyades, Praesepe and Coma. McLure and Twarog (1977) conclude that this scatter is intrinsic and probably attribuable to abundance differences. Without denying this effect we should like to remark that this diffuse appearance is exactly what we will see in an old cluster where the stars were formed at different epochs. We must never forget that the main sequence locus varies with time as may be seen from the diagrams given by Iben (1965, 1967). Other explanations for the diffuse character of the main sequence using the presence of binaries or rotational effects should play a much less important role for both these influences decrease with increasing age.

The last intriguing problem concerning NGC 188 (and other old clusters) may be called the abundance problem. We find intrinsic vatiations of CN strength correlated with UV excesses (McLure and Twarog, 1977) for the main sequence stars and different metallicity parameters for the later type giants (Gottlieb and Bell, 1972) which suggest the presence of normal , metal-rich and super-metal-rich stars in the cluster. The current explanations propose the mixing of processed material towards the surface or intrinsic variations in the initial cluster cloud. It is also possible that processed material from supernova explosions, planetary nebulae, stellar winds, etc...participates in the repeated formation of new stars.

A possible solution.

Our main conclusion from this incomplete survey of difficulties with the age calibration from isochrones, the magnitudes of late type giants, the presence of blue stragglers, the dispersion of the main sequence stars, the understanding of the chemical composition without forgetting the existence of 4 W UMa stars in NGC 188 is the following :
All these difficulties may be solved if it is true that different bursts of star formation have taken place at different epochs in the cluster. The periodicity of these bursts is difficult to establish, but a succession of 3 bursts with intervals of about 1 - 2 x 10^9 years would be sufficient to explain the different "anomalies". The last burst should have been at the origin of the 4 W UMa stars and have occurred not longer than some times 10^8 years ago.

Random or non-random axes?

We now come to the second point raised at the beginning, which concerns the hypothesis of a random or non-random distribution of the orbital axes. If the first hypothesis is true we may expect the presence of 4 contact binaries in the cluster. If the seond hypothesis is true a total number of 20 or 30 contact binaries has to be expected, with the statistically difficult problem why no W UMa stars are observed in the amplitude range $\Delta m < 0.45$. We already discussed the problem of aligned orbital axes some years ago (Van 't Veer, 1975a). We then concluded from a study of the bibliography on the subject that young galactic clusters may show a preferred orientation of the spin of their members. Little work seems to have been done on this subject since that time. So if we still admit this conclusion we find no reasons to suppose that there is a preferred orientation of the axes in a galactic cluster as old as NGC 188. However the facts seem to contradict this view and perhaps we may reverse this question by saying that the observation of 4 W UMa stars with inclinations between 90° and 75° in NGC 188 is not a simple coïncidence but a convincing piece of evidence for the hypothesis of preferred orbital orientation of binary stars in certain groups. It may perhaps be considered as a supplementary demonstration that these 4 contact binaries were formed only recently and still remember the original vortex.

References.

Barry,D.C., Cromwell,R.H., Hege K., Schoolman,S.A : 1981, Astrophys. J. 247, 210.
Demarque,P.: 1979, I.A.U. Symp. N° 85, ed. Hessen,J.E., p. 281.
Eggen,O.J., Sandage,A. : 1969, Astrophys. J. 158, 669.
Gottlieb,D., Bell,R. : 1972, Astron. Astrophys. 19, 434.
Heuvel,E.P.J. van den : 1968, Bull. Astron. Inst. Netherlands 19, 326.
Hintzen,P., Scott,J., Whelan,J. : 1974, Astrophys. J. 194, 657.
Hoffmeister,C. : 1964, Inf. Bull. Variable Stars No. 67.
Huang,S.S. : 1966, Ann. Astrophys. 29, 331.

Iben,I. : 1965, Astrophys. J. 141, 993.
Iben,I. : 1967, Astrophys. J. 147, 624.
Liller,M. : 1979, IAU Symp. n° 85, ed. Hessen,J.E.p.357.
McLure,R.D., Twarog,B.A. : 1977, Astrophys. J. 214, 111.
McCrea,W.H. : 1964, M.N.R.A.S. 128, 147.
Mestel,L. : 1968, M.N.R.A.S. 138, 359.
Rucinski,S. : 1980, Acta Astron. 30, 373.
Sandage,A. : 1961, Astrophys. J. 135, 333.
Sandage,A., Eggen,O.J. : 1969, Astrophys. J 158, 685.
Shapley,H.: 1948, Harvard Obs. Monographs 7, 249.
Stauffer,J.R. : 1980, Astron. J. 85, 1341.
Strömgren,B. : 1952, Astron. J. 57, 65.
Struve,O. : 1950, Stellar Evolution, Princeton University Press.
Twarog, B.A. : 1978, Astrophys. J. 220, 890.
Van 't Veer,F.: 1975, Astron. Astrophys. 40, 167.
Van 't Veer,F. : 1975a, Astron. Astrophys. 44, 437.
Van 't Veer,F. : 1976, TAU Symp. N°73, eds. Eggleton et al., p.343.
Van 't Veer,F. : 1979, Astron. Astrophys. 80, 287.
Van 't Veer,F. : 1980, Acta Astron. 30, 381.
Vilhu,O., Rahunen,T. : 1980, IAU Symp. N°88, eds. PLavec,M.J. et al. p.491.
Wheeler,J.C. : 1979, Astrophys. J. 234, 569.

https://doi.org/10.1017/S0252921100100600 Published online by Cambridge University Press