MASS AND LUMINOSITY FUNCTION OF THE PLEIADES

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ABSTRACT

From a proper motion survey by Pels and photometric measurement of selected stars it was found that the Pleiades cluster extends till at least 4°.6 from the centre, corresponding to 10 pc at a distance of 125 pc. It turns out that the luminosity function of the Pleiades is a function of the distance to the centre, the proportion of faint stars increasing with this distance. Because of this, the luminosity function as it was determined before flattened towards fainter stars, whereas for the total field with a diameter of 20 pc one finds a luminosity function that is still increasing at the faint end. Flare star observations in the Pleiades field show that the increase amounts to at least a factor 20 in the mass range 2 to 0.4 $M_{\odot}$. Accurate proper motions of stars in the projected central field show a dispersion of velocities in the cluster of 700 m/sec. This could indicate a total mass of the Pleiades cluster of the order of 2000 $M_{\odot}$.

I. NEW MEMBERS

In a survey for new members in the Hyades by Pels (1975) the field of the Pleiades was included. From this survey several possible members were found. The majority of these stars have been measured photometrically in 1977 in the Walraven 5-colour system (described by Lub and Pel, 1977). From this a total number of 85 new members were found, ranging in magnitude from 6 to 13 (most of the brightest were already known by Trumpler, 1921). The stars till m_{pg} = 12.6 now known as cluster members are given in fig. 1. New members were found till 10 pc out of the centre, 4°.6 on the sky. A search for members even further away is difficult: less than one of every 200 stars brighter than m_{pg} = 12.5 can be expected to be a member.

James E. Hesser (ed.), Star Clusters, 157–163.

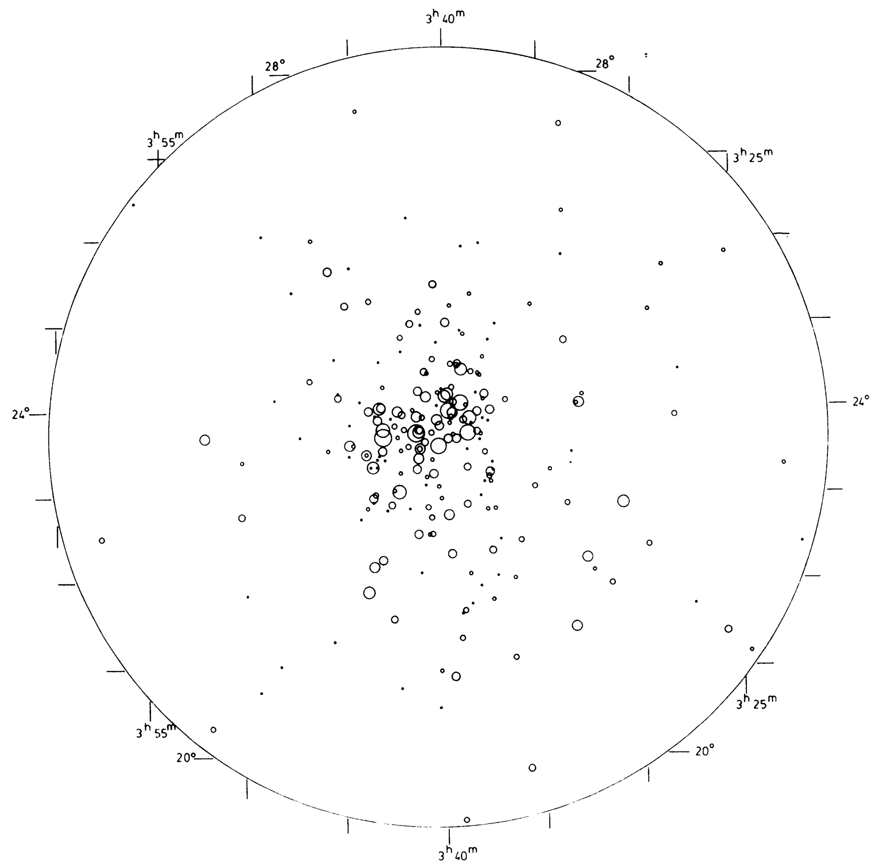

Fig. 1. Map of the Pleiades. Coordinates: 1900

II. MASS DISTRIBUTION

The data of fig. 1 were used to determine spatial mass distributions for two different groups of stars: those more massive than 1.5 $M_\odot$ and those between 1.5 $M_\odot$ and 0.8 $M_\odot$. The spatial densities were derived by numerical differentiation of the surface densities and are given in fig. 2. Also in fig. 2 is the distribution of a third group, the flare stars, for which the data are taken from Haro (1976). The righthand part of fig. 2, where the distributions are normalized on their halo's, shows clearly the strong mass segregation. The density in the centre for stars with masses below 1 $M_\odot$ is so low, that the likelyhood of finding one star per magnitude interval there is small. Statistical uncertainties make it difficult to give densities for the small volume occupied by the massive stars. It looks like there are no stars in the cluster centre between m_{pg} = 11.5 and m_{pg} = 12.5.

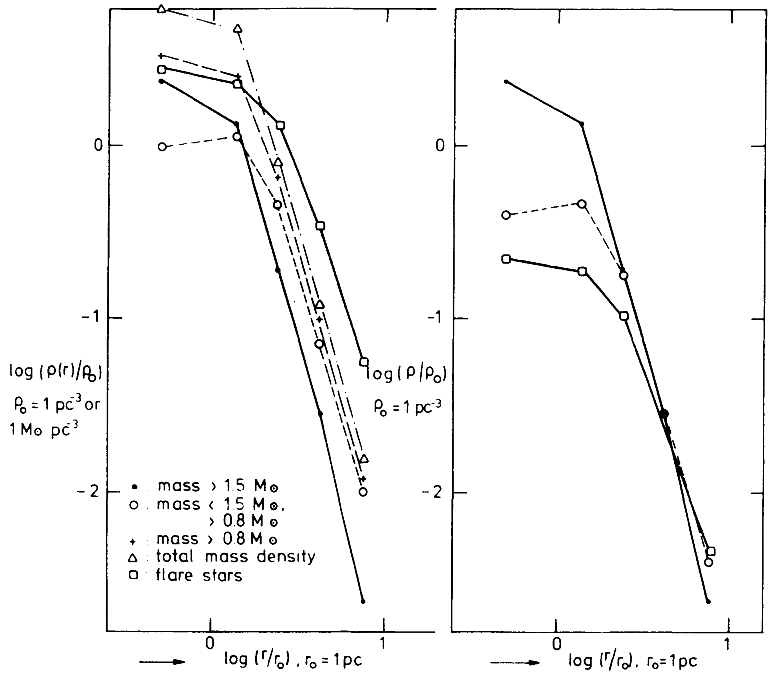

Fig. 2. Spatial densities

III. THE LUMINOSITY FUNCTION

As a result of the strong mass segregation one expects the luminosity function to vary considerably over the cluster. The luminosity functions of the central area (1 pc radius) and the total cluster are given in fig. 3. Apart from data on the Pleiades also two standard luminosity functions are plotted: one by Luyten (1967) based on large proper motion stars, and one by Taff (1974) based on 62 open clusters. The central field of the Pleiades shows a flattening luminosity function: from $m_{pg} = 7$ to $m_{pg} = 14$ the total number of stars per magnitude interval as projected within a circle of 1 pc radius varies randomly between 3 and 8. The luminosity function by Taff shows a strong flattening beyond $M_{pg} = 4$. As usually only cluster centres are available for deriving this type of data, the flattening as observed by Taff may very well be a result of mass segregation. However, also evolutionary effects can have had their influences, as Taff used clusters of very different ages.

If we now look at the total cluster, we see that the total number of stars per magnitude interval is still increasing: from 15 at $m_{pg} = 7$ to 55 at $m_{pg} = 12$, and an estimated number of 83 at $m_{pg} = 14$. This estimate is based on the distribution of the 1 $M_\odot$ stars and extrapolated from the total number of projected members in the centre from Herz-

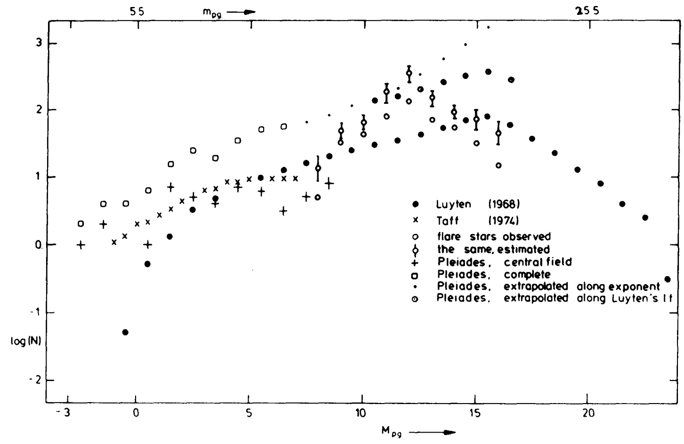

Fig. 3. Luminosity functions

sprung's (1947) data.

A luminosity function is often given by an exponential function. For the increasing section of his luminosity function Taff gave the following relation:

$$\log(dN/d\text{mass}) = -2.74 \log(\text{mass}) \pm 0.07 \text{ for } M_{pg} \text{ between } -1 \text{ and } +4.$$

For the range of the luminosity function of the Pleiades that is not affected by stellar evolution I found:

$$\log(dN/d\text{mass}) = (-2.71 \pm 0.27)\log(\text{mass}) + (2.414 \pm 0.011) \text{ for } M_{pg}$$

between 1.5 and 6.5.

Also plotted in fig. 3 are data as given by Mirzoyan et al. (1977) on the distribution of flare stars. Two numbers are given, the observed and the estimated numbers. When comparing the flare stars in the Pleiades with those in Orion, it is clear that the flare activity is strongly influenced by the age of the stars. The younger Orion flare stars are all more massive. We assume that in the magnitude interval corresponding to the top of the frequency distribution of the flare stars their number is close to the total number of cluster members. Comparing the estimated number of stars for the top of the distribution between m_{pg} = 16 and 18 with the exponential luminosity function, we see that the luminosity function is still increasing accordingly. As these stars are not yet on the ZAMS, a direct mass estimate from their magnitude is not possible. If we assume that those stars are not more than one magnitude too bright, then their masses will be between 0.3 $M_\odot$ and 0.5 $M_\odot$.

IV. INTERNAL MOTIONS

Internal motions for stars till $m_{pg} = 12.5$ in the central field of the Pleiades were derived by Vasilevskis, Van Leeuwen et al. (1979). As their mean errors of 0".2 per millenium were much better than the internal dispersion in proper motions, 1".0 per millenium, I was able to derive the true dispersion in transverse and radial directions. They were compared with the model described by Oort and Van Herk (1959). For the centre it assumes a rapid decrease in the dispersion of the transverse velocities with increasing distance. The results together with the best fit of the model are given in Table 1. The dispersion of velocities in the centre is found to be 700 m/sec in each coordinate. From the mass distribution it was also possible to find the mean mass for stars to which that velocity dispersion applies, 2 $M_\odot$ per star.

Table 1. Radial and tangential velocity dispersions.

Units: "/millenium

	Observed		Model	
	$\langle\mu_r^2\rangle^{\frac{1}{2}}$	$\langle\mu_t^2\rangle^{\frac{1}{2}}$	$\langle\mu_r^2\rangle^{\frac{1}{2}}$	$\langle\mu_p^2\rangle^{\frac{1}{2}}$
0 - 0.5 pc	0.98	1.03	0.98	0.95
0.5 - 1.0 pc	0.98	0.86	1.02	0.86
1.0 - 1.5 pc	1.04	0.69	1.05	0.72

Comparing the potential energies of stars in the centre with the above found kinetic energies, it appears that the amount of the mass needed in the cluster is higher than assumed before. It seems more likely to be 2000 $M_\odot$ than the 600 to 800 $M_\odot$ mentioned by Jones (1970). A mass of 800 $M_\odot$ in the known cluster volume would give reason to a very shallow potential well, in which one expects to find stars of 2 $M_\odot$ also on the edges of the cluster.

The total mass of 2000 $M_\odot$ is also arrived at by extrapolating the luminosity function to stars of approximately 0.08 $M_\odot$; this gives a total of 10000, distributed in a volume of some 5000 pc^3.

V. FUTURE WORK

My work now in progress consists of accurate determination of proper motions in the largest practible field for stars till $m_{pg} = 14.5$, and determination of the photometric properties of the member stars found. The proper motions and distribution data will be used in combination with analytical and numerical cluster models.

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DISCUSSION

KING: One thing is to encourage you to look at the fainter stars. It would appear to me that you've gone only to about thirteenth magnitude and there's plenty of room for more work on fainter stars. I would also comment that the virial theorem almost always gives the wrong answers.

VAN LEEUWEN: Yes, I know.

KING: I think that there are other methods of looking at the dynamics of the central region of the cluster that will tell you how much mass is in the center of the cluster. But you cannot determine a mass in a region where you don't have observations. So, because your observations are in the center, you can determine the mass in the center, and I would encourage you to do that in as clear a way as possible.

VAN LEEUWEN: Well, I'm busy with it now.

FREEMAN: Can I just add a quick comment on that virial theorem thing, as well. Particularly in a situation where you have a velocity dispersion decreasing with radius, the virial theorem will nearly always give you an over-estimate, not an under-estimate.

VAN LEEUWEN: Yes.

KEENAN: If you assume that a mass of $\sim 10^4 M_\odot$, which is the sort of value you seem to favour, if I understood you correctly, how does that value of the outer radius, approximately 10 pc, compare with a classical King or Van Hörner tidal radius?

VAN LEEUWEN: Oh, that radius stops at the order of 25 pc.

KEENAN: I see, thank you.

FREEMAN: I'll just ask one more. Did you find any sign of rotation?

VAN LEEUWEN: No, but it's not yet possible to detect it. I can quite safely say that we've got almost the most accurate data for the Sun that one can obtain and its simply not possible to detect rotation by means of those data. You can only do that from field stars because of the reduction methods that are used for this type of relative proper motion work, and dispersions of field stars are such that they don't allow you to detect any. It is possible, though, to detect any differential rotation later on when we've got bigger fields. But absolute rotations are very difficult.

BOK: What distance did you use for the Pleiades?

VAN LEEUWEN: Oh, a 125 pc.

BOK: 125!

VAN LEEUWEN: But it really doesn't make such a difference.

BOK: No.

VAN LEEUWEN: But a 125 is quite safe.

BOK: Yes.