M DWARFS AT LOWER z DISTANCES

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Twelve years ago, during the International Summer Course at Lagonissi, Bart Bok (1966) presented a paper "Desiderata for Future Galactic Research". He pointed to the importance of studies in the galactic polar caps which would allow us, as he hoped, to determine some basic data for galactic structure.

The significance of his statements was demonstrated already in the following years when the gradual increase of our knowledge of the objects in the solar neighbourhood was suddenly interrupted by new observational data from which diverging conclusions have been drawn. Never before have such controversial opinions on problems in the vicinity of the sun been so eagerly discussed: A formerly unknown numerous population of low-velocity red dwarfs, the mass density resulting from stars three times that formerly thought, a remarkably increased luminosity function - yes or no? Obviously, the controversies have smoothed down again during the last months. But what is the situation after this troubled period? Which problems are still unsolved? Which promising programmes will be proposed? I think this Joint Discussion is justified in 1976!

From studies of stars at high galactic latitudes, the stellar density distribution perpendicular to the galactic plane can be determined. Furthermore, such investigations yield the possibility of deriving the luminosity function for intrinsically faint stars near the sun. In these areas, the number of contaminating distant giants is at a minimum.

Bart Bok (1966) put special significance on the value of the average density of matter in the galactic plane near the sun. At that time Oort's value (1965) of 0.15 solar masses per cubic parsec was accepted. As the total mass of known stars came out to about 0.06 solar masses and the density of interstellar matter was estimated to about 0.02 or 0.03 solar masses, at least 0.06 solar masses per cubic parsec remained unaccounted for. That is the well-known "problem of the missing mass" in the solar neighbourhood!

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TABLE I

Observations of a large space density of M dwarfs in the directions of the galactic poles

Author(s)		NGP SGP	Squ. degr.	Nos. of stars	Objects	Observed quantities	x	Results
Sanduleak	1964	N	120	1261	M stars, $12<V<17$	Colours V-I	3	
Pesch, Sanduleak	1970	N			Sanduleak stars	Proper motions		Low velocities
Weistrop	1972	N	13.5	13820	$12<V<18$	B,V photogr.	5-10	$10<M_V<13$ (15)
Murray, Sanduleak	1972	N		21	Sanduleak stars $m_V = 13\text{-}16.5$	Proper motions	5	Low velocities
Pesch	1972	N		21	Sanduleak stars small μ, $9\leq V\leq 15$	dM, spect. types U,B,V photoel.	2	Low velocities
Sanduleak	1976	N	190	273	Sanduleak stars M3 and later	crude sp. types crude m_R		
Gliese	1972	S	550	75	very red stars $m_{pg} = 15.0\text{-}17.3$	μ, colour class (Giclas et al.)	>1	"normal" velocity dispersion
D.H.P. Jones	1973	S	165	22	McCarthy stars (1964); $11\leq m_V\leq 15$	Colours	∿1	"normal" velocity dispersion
Thé, Staller	1974	S	238	96	Proper motion stars, M2-M4	Spectral types μ, m_{pg}	1-1.5	"normal" velocity dispersion
Dolan	1975	S			Thé-Staller stars		?	Space density uncertain

Does this mass come from stars of very low luminosity, from a large percentage of faint red degenerates, from dark stars, from faint companions or unseen companions, from molecular hydrogen? Have we to make a marked correction to the luminosity function?

Different possibilities have been studied without discovering the "missing mass". However, a very new development was initiated in 1964 by Sanduleak who detected over 1200 faint red stars in a 120 square degree area in the north galactic polar region. The low dispersion plates did not permit a luminosity class separation. But, assuming that the great majority of these objects are dwarfs, the total space density of M dwarfs was estimated to be nearly three times the number previously thought to exist.

Luyten's luminosity function (1968), derived from the frequency of stars with large proper motions, contradicted this assumption. However, Weistrop (1972a, 1972b) also detected large numbers of faint red stars near the NGP and, from star counts as a function of colour and apparent magnitude, she derived a luminosity function of M dwarfs several times larger than Luyten's function, at least between $+10 < M_V < +13$ or even $M_V < +15$.

Further investigations seemed to confirm the existence of a numerous population of low-velocity M dwarfs in the solar neighbourhood hitherto unknown. Table I shows the essential data of these publications. Special attention should be given to column "x" which states whether or not the resulting space density of red dwarfs is higher than previously thought: the resulting space density is about x times that given by Luyten's luminosity function.

From the observations cited in Table I, the following conclusions were drawn: In the luminosity range $+10 < M_V < +15$ a population of red low-velocity stars exists in the solar neighbourhood which is derived to be two to ten times as numerous as given by Luyten's luminosity function. Such objects with small proper motions could not be detected by Luyten and by Giclas in the extensive searches for faint stars with annual proper motions exceeding 0"2. They seemed to be highly concentrated to the galactic plane in a thin layer similar to the interstellar gas and the B stars. Therefore, the total mass density in the vicinity of the sun would not be 0.15 $M_\odot$ pc^{-3} but even 0.21 $M_\odot$ pc^{-3} (Oort, 1965). Nevertheless, Weistrop (1972b, 1974) and Veeder (1974) showed that the existence of this M-dwarf population seemed to yield the "missing mass". About two thirds of the total mass appeared to be due to the M dwarfs.

Near the SGP, since Luyten (1960) no programme comparable to Sanduleak's and to Weistrop's investigations has been carried out. The mass density derived from the few data seemed to be somewhat lower than in the NGP regions.

The new results implied either that most of the mass in the disk component formed into stars only recently or that stellar velocity

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dispersions are not closely correlated with age (Biermann, 1974; Biermann and Tinsley, 1974). The assumption that the existence of this population had solved the problem of the missing mass created new problems related to the stability of the galactic disk (M. Schmidt, 1975).

From the beginning of these discussions the new results were called in question by Luyten. The discrepancy between his luminosity function and the frequency of red dwarfs assumed from the observations in the vicinity of the NGP was too amazing. Weistrop's investigations (1972a, 1972b) were the most convincing evidence for the overabundance of M dwarfs. These studies were virtually based on colour measurements. But even if red stars are classified decidedly as dwarfs, moderate errors in spectral type or colours will produce fairly large errors in the derived absolute magnitudes and distances. Among red dwarfs an error $\Delta(B-V) = +0^{m}.1$ corresponds roughly to $\Delta M_V = +1.3$ which reduces the derived distance to 55 per cent. Therefore, systematic errors in the observed quantities can be responsible for wrong values of the supposed star density.

The colour system used by Weistrop (1972a, 1972b) has been challenged by Luyten (1974) and by Jôeveer (1975). Finally, Weistrop herself (1975, 1976a) and Faber et al.(1976) could show that the original (B-V) values actually had been determined too red. It appears now that Weistrop's observations are compatible with the previously assumed data.

In further investigations the results obtained by Sanduleak, Murray/Sanduleak, Pesch and Gliese also have been questioned or corrected (Gliese, 1974; Jôeveer, 1974; Koo and Kron, 1975; Weistrop 1976b, 1976c).

Have we now returned to the status of 1964 before these discussions started? Have the papers cited in Table I proved to be useless? I do not think so - numerous observational programmes have been initiated by these controversies.

We have today a fairly complete knowledge of the objects with large proper motions in the galactic polar caps. On plate pairs taken with the Forty-eight Inch Schmidt-Telescope, Luyten detected many thousands of red stars with $\mu > 0''.179$ annually between $m_{pg} = 13$ and 21. The SGP catalogue (Luyten and La Bonte, 1973) and the NGP catalogue (Luyten, 1976) also give crude apparent magnitudes m_{pg} and m_R and estimated colour classes (k, k-m, m). Near the SGP Giclas et al. (1972, 1973, 1975) have listed several hundred "very red objects" (mostly colour class "+4"), the vast majority with proper motions exceeding $0''.06$ annually.

Proper motions, magnitudes and colours of so many red stars - could these data be a basis for solving our problems? The large number of objects in these proper motion surveys did not permit more than crude estimates of magnitudes and colours which may vary systematically among different plate pairs and among different parts of the sky.

TABLE II

Mean differences between the m_{pg} estimated by Luyten or by Giclas and the photoelectric B measured by Eggen near the SGP

Luyten and La Bonte (1973)			Giclas et al. (1972)		
m_{pg}(LP)	N	m_{pg}-B	m_{pg}(G)	N	m_{pg}-B
10.0 - 12.9	42	-0.01	< 13	82	+0.82
13.0 - 14.9	61	-0.20	13.0 - 15.9	79	+0.39
15.0 - 16.5	34	-0.54	16.0 - 17	18	+0.11

Within 10° of the SGP, these estimates have been compared with B and (B-V) data from Eggen (1976a, 1976b) who had measured the (UBVRI) photometry of the known M dwarfs brighter than V = 15 and with proper motions exceeding 0".096 annually. Table II does not show only systematic differences up to $0^m.8$ among the three sets of magnitudes but also significant scale differences. The (B-V, colour class) diagram of Fig. 1 gives evidence of the dispersions among the B-V of the same colour class

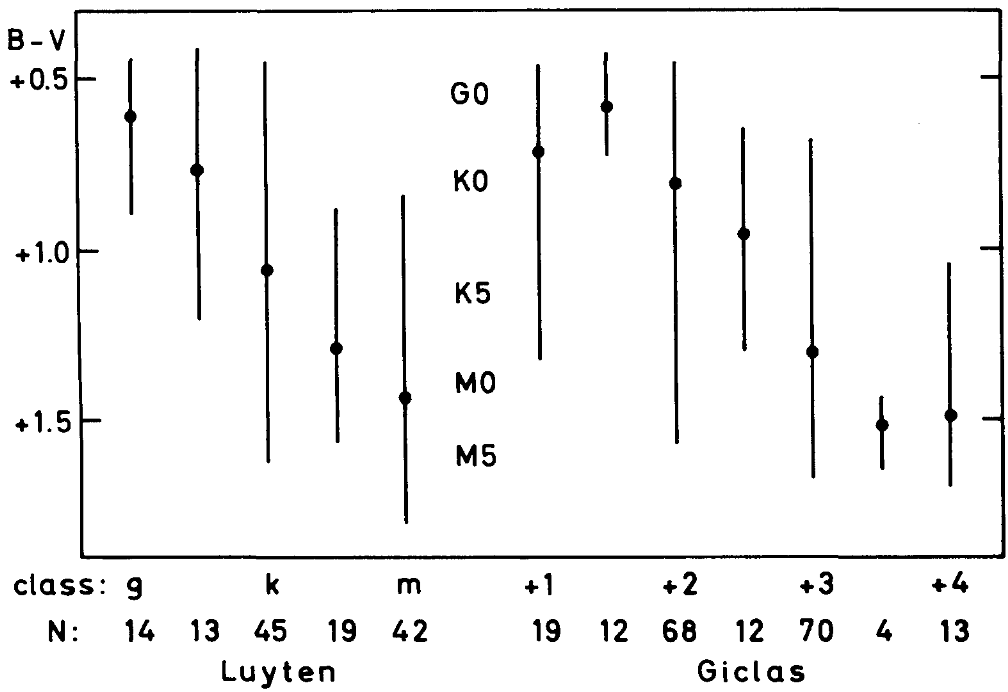

Figure 1. [B-V (Eggen), colour class (Luyten, Giclas)] diagram. Maximum, minimum, mean (B-V), and numbers N of stars for each colour class.

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TABLE III

Observed (O) and computed (LM) numbers of red proper motion stars within 10° of the South Galactic Pole

Parallax	0″10 ≤ μ < 0″20 O	0″10 ≤ μ < 0″20 LM	0″20 ≤ μ < 0″30 O	0″20 ≤ μ < 0″30 LM	0″30 ≤ μ O	0″30 ≤ μ LM
B = 12.26 - 14.25						
> 0″095					1	1
0″051-0″095	1		1			3
.039 .050	1	1		1		3
.029 .038	1	3	1	2	3	4
.022 .028	2	8	3	5		4
.016 .021	4	29	7	10	1	6
.010 .015	13	54	15	10	1	3
.005 .009	5	18		0.5		
Sum	27	113	27	28.	6	24
B = 13.96 - 15.95						
> 0″095						1
0″051-0″095	1	1		1	1	4
.039 .050		1		1	1	4
.029 .038	1	4	1	3	8	5
.022 .028	5	10	7	6	5	6
.016 .021	18	39	23	13	5	8
.010 .015	28	119	13	21	7	6
< 0″010	26	236	8	2	1	
Sum	79	410	52	47	28	34

and of the remarkable overlap of the adjacent classes (see also Gliese, 1976; Table II and Table III). Unfortunately, there are still no photoelectric data available for comparisons with the estimated magnitudes and colours of stars fainter than $m_{pg} = 17$.

We have made several attempts to compare the observed numbers of red stars with large proper motions with numbers computed on the basis of assumed luminosity functions and velocity distributions. The results are not very encouraging since we do not know the real velocity distribution of the low-luminosity stars and since the observed magnitude scales and colours may have systematic errors (Gliese, 1976). Certainly, it has been shown that Luyten's numbers of very faint proper motion stars detected in both galactic polar caps are in contradiction to a dense population of intrinsically faint low-velocity stars. But, on the other hand, it has not been possible to confirm definitely Luyten's luminosity function in this way.

Many of our difficulties will become evident when, finally, I show you in Table III some results from Eggen's data (1976a, 1976b) which he had measured in a 315 square degree area (≈ 0.76 per cent of the whole sphere) at the SGP. In two magnitude ranges $12.26 \leq B \leq 14.25$ and $13.96 \leq B \leq 15.95$ the numbers of red objects with large proper motions are given in different distances. The observed numbers in the columns "O" are based on the photometric parallaxes published by Eggen (1976b). Columns "LM" have been computed with Luyten's luminosity function (1968) and with a velocity distribution like that of the early M dwarfs ("McCormick stars"). The data are subdivided into three proper motion ranges from 0".10 to 0".20, 0".20 to 0".30 and proper motions exceeding 0".30 annually.

There is no agreement between computed and observed numbers of the objects with smaller proper motions. We may suppose that this discrepancy is due to incomplete knowledge of the stars with μ < 0".20, but we cannot yet prove it. Significant numbers of members of a low-velocity population would appear only in distances nearer than 25 pc. Eggen stated that no support is found for the recently suggested superabundance of low-velocity M dwarfs near the sun.

But we are looking for the true luminosity function in the solar neighbourhood. Doe these numbers confirm the Luyten-McCormick model? In the immediate vicinity of the sun they do not! Only a few proper motion stars have been found nearer than 26 pc which means in a volume of about 500 pc^3. In larger distances, the differences "O-LM" fluctuate and it appears to be impossible to verify the observed data exactly by a simple model of one luminosity function with one uniform velocity distribution for stars of all luminosities and for different distances from the galactic plane.

Most of the stars are nearer than 100 pc to the galactic plane, but a uniform density distribution should not be assumed for all distances. On the other hand, with increasing z, an increasing velocity dispersion can be expected. Furthermore, we know of the correlation between velocities and ages (Wielen, 1974), but what do we know of the intensities of Ca II emission as indicators of the ages of these dwarfs? Last, not least, uncertainties of the photometric parallaxes can introduce serious biases into the data in Table III. Random and systematic errors must be considered. All these effects need a careful analysis. But the statistically low numbers of objects in our samples leave some doubt whether or not such a detailed investigation can solve the

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problems.

Nevertheless, Eggen's set of data very clearly shows which observations are required additionally.

Much progress would be made by the measurement of reliable trigonometric parallaxes of an unbiased sample of faint red stars in both polar caps. With eager expectation we are looking forward to the papers by Murray and by Strand. Sanduleak's new catalogue of 273 faint stars of spectral types M3 and later near the NGP (1976) presents such a sample of objects recommendable for further investigations. Luyten (1976b), already has shown that there are stars among them without noticeable proper motions.

It is desirable to determine spectroscopic and photometric data for a large number of faint red objects in both galactic polar regions to supplement the knowledge of their proper motions. I think that D.H.P. Jones and Donna Weistrop will report on further studies of objects at the faint end of the luminosity function near the NGP. Pesch will report on a survey for M dwarfs in a region of the SGP to parallel Sanduleak's work in the north. Furthermore, I have been informed that Warren is measuring the U, B, V data of the very red Giclas stars in the south.

The non-existence of the numerous population of low-velocity red dwarfs seems to be confirmed. But what do we know about the real velocity distribution of the low-luminosity red stars? What is their space density? What is the luminosity function of M dwarfs intrinsically fainter than $M_V = 13$? What do we know about the frequency of late degenerates? How shall we solve the problem of the missing mass now? By assuming a lower value for the total mass density, as our colleagues from Tartu do? Let us begin our Joint Discussion!

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