THE PROBLEM OF A HIGH SPACE DENSITY OF M DWARFS IN THE SOLAR NEIGHBOURHOOD

The problems concerning M-type dwarfs (see Staller and Thé, *Bull. Astron. Soc. of India*, **3**, 38, 1975) were discussed on August 25, 1976 at a Joint Discussion of I.A.U. commissions 25, 33 and 45 during the General Assembly of the I.A.U., held at Grenoble, France. The title of the Joint Discussion was Galactic Structure of the Galactic Polar Caps. Here a short report is given of the discussion on the reality of the high space density of M-type dwarfs in the solar neighbourhood found by several investigators.

In order to refresh our memory, I will begin with a short summary of the problems concerning this space density. Murray and Sanduleak (MS), (M.N.R.A.S., **157**, 273, 1972), have studied the space distribution of M-type stars in the direction of the North Galactic Pole (NGP). Assuming that the M-type stars with proper motion smaller than 0.18″ / year, the socalled low-velocity stars, all are M dwarfs, they obtain a space density of 0.23 stars/pc^3. This value is about 4 times larger than that found by Luyten (M.N.R.A.S., **139**, 221, 1968). Further more, they have found that the velocity dispersion of the low velocity stars is very small (10 - 15 km/sec) as compared to that of normal M dwarfs (20 - 25 km/sec). The mass density of the M dwarfs is enough to explain Oort's missing mass ("*Galactic Structure*," Univ. of Chicago Press, Chicago, p. 445, 1965). The results of MS are supported by those of Miss Weistrop (*A.J.*, **77**, 366, 1972), who has made a study of the distribution of a very large number of stars in the NGP region, using Mt. Palomar Schmidt plates. This study has been made in Johnson's (B,V) system. P. Pesch (*Ap. J.*, **177**, 519, 1972) and B.F. Jones (M.N.R.A.S., **159**, 3P, 1972), have obtained results in general agreement with those of MS.

The results of studies of M-type dwarfs in the direction of the South Galactic Polar (SGP) region are different. Gliese (*A.* & *A.*, **34**, 147, 1974), Thé and Staller (TS) (*A.* & *A.* **36**, 155, 1974), and D.H.P. Jones (M.N.R.A.S., **161**, 19P, 1973) have obtained values for the space density of M dwarfs which are much smaller than that of MS. The result of TS, 0.06 stars/pc^3, is based on M-type stars having proper motion larger than 0.18″/year, and is corrected for incompleteness of the data. It is of interest to mention that Dolan (*A.* & *A.*, **39**, 463, 1975), using the list of stars given by TS and based on a new matrix method for deriving space densities has come to the conclusion that the space density of M dwarfs in the SGP region derived by TS is not necessarily in disagreement with the higher density results derived by MS for the NGP-region. It is of interest to study the consequences of Dolan's conclusion. At the Joint Discussion, Turon stated that she has arrived at similar results using an improved Dolan method.

Based on a space density of 0.06 stars/pc^3 (TS), one can expect a total number of 32 M dwarfs within a sphere of radius 5 pc centered at the Sun. Within this sphere, a total number of 40 M dwarfs of spectral types M0-M8 is known (Van de Kamp, *Vistas in Astronomy*, **19**, 225, 1975). These stars have visual apparent magnitudes between 8.0 to 14.0. If Dolan-Turon's result is correct then we should expect a total of about 130 M dwarfs within this sphere. It is unlikely, even if we consider the possibility that there are M dwarfs hidden as faint members of brighter stars, or that the M dwarfs are binaries, that there are so many relatively bright M dwarfs not yet discovered within this 5 pc sphere. At the Joint Discussion this was pointed out by Luyten.

It is very important to give an answer to the question whether there is really a high space density of M dwarfs in the solar neighbourhood, before one tries to explain theoretically the luminosity function of M dwarfs such as published by Sanduleak (*A. J.*, **81**, 350, 1976); one should first study the possibility that there are experimental errors which make the space densities becoming too high. The result of the calculation of the space-density depends very sensitively on the accuracy of the mean distance of the stars considered. If the distances have been estimated using a relation between, for instance, M_V and $(B-V)_0$, a wrong colour equation in the photographic photometry will seriously affect the determination of the mean distance of the stars. At the meeting of commission 25, King showed that the colour-indices of Weistrop's red stars are too red, so that the distances are too short, and the densities too large. After correction Faber et al (*A. J.*, **81**, 45, 1976) arrive at space densities consistent with a low local space density of M dwarfs such as derived by Luyten (1968). A similar study has recently been published by Weistrop (*A.J.*, **81**, 759, 1976). She shows that the (V-I) - colour indices of Sanduleak (1976) are too large. The consequence of this systematic error is too high a space density of the M-dwarfs and an erroneous luminosity function.

A photometric study of 9 M dwarfs in the NGP region by Weistrop (*A. J.*, **81**, 427, 1976) in Kron's R, I-system shows that indeed the space density of M dwarfs in the solar vicinity should be lowered to 0.057 stars/pc^3 in agreement with the result of TS in the SGP region. Another approach to the problem has been reported by Koo and Kron (P.A.S.P., **87**, 885, 1975). They obtain spectrophotometric parallaxes for 5 brighter MS stars. Their results show that indeed the MS mean distance of the M dwarfs must be enlarged by a factor of about 2, and the space density reduced by a factor of about 8. We then arrive at a not unreasonable value of the space density of 0.04 stars/pc^3. A more direct method has been applied to the high density problem. Strand reports that with United States Naval Observatory astrometric telescope he has determined the trigoniometric parallaxes of 5 stars of Sanduleak's list. The mean value of these parallaxes is 0.″007, as compared to the mean parallax of 0.″02 derived by MS. Again, from Strand's work we must conclude that there are no abnormal space densities in the neighbourhood of the Sun. It should of course be mentioned here that the star samples used by Weistrop, by Koo and Kron, and by Strand are quite small. But the agreement of their results suggest that the space density of M dwarfs in the solar neighbourhood is not high. It should be mentioned that Smethels (Thesis, Case Institute of Technology, Cleveland), has obtained a space density of M dwarfs comparable to that of MS. This result is based on a red-spectral - region survey of 1720 square degrees of the Southern sky with the 6° prism of the Curtis - Schmidt telescope at Cerro Tololo. Despite Smethel's result, however, one tends to believe that the space density of M dwarfs in the solar vicinity is of the order of 0.06 stars / pc^3, such as was calculated by Luyten in 1968.

The question now is whether we should abandon the idea of high space density of M dwarfs at all. I think we may do so for brighter M dwarf stars, but then we have no solution of the problem of the missing mass. Despite that Einasto and his group have some doubts on the existence of a missing mass in the solar neighbourhood, we should study Kumar's suggestion of the possibility that there are many stars in the mass range 0.01-0.07 $M_\odot$ in our galactic space still to be discovered, and which can provide extra mass for the solution of Oort's missing mass problem. A new support for the existence of such stars has been given by Van de Kamp's (*Ann. Rev. of A. and Ap.*, **13**, 295, 1975) results of his study of unseen companions of stars in our immediate surroundings. BD+68° 946, Barnard's star, and BD+43°4305 have unseen companions with masses lying in the above mentioned range. At a colloquium held at the Amsterdam Astronomical Institute, van de Kamp showed that, if one makes a statistical study of the unseen companions of seen stars up to 25 pc from the Sun, there is a possibility that Oort's missing mass is hidden as unseen companions.

Van de Kamp's results do not mean, however, that the missing mass problem is completely solved. We know that the semi-theoretical determination of the density of matter (ρ_{dyn}) in the solar neighbourhood must still be improved. Several working groups are at present busy determining a new value of ρ_{dyn}. Radford, for instance, (private communication) has obtained a quite high preliminary value: 0.30 $M_\odot/pc^3$. We are anxious to know at what value other working groups (Hill et al., *Memoirs* R.A.S., **82**, 69, 1976), Osburn (Venezuela), Florsch (Strasbourg) will arrive.

At the Amsterdam Astronomical Institute a blink-survey of red stars on copies of Mt. Palomar Schmidt blue and red South Galactic Pole plates, up to the plate limit ($V \simeq 20$ mag) is in progress. This should provide information on the space density of black dwarfs in the solar neighbourhood. We are wondering whether the many faint red stars we have found in our survey region (6 sq. degr.) are distant normal main sequence M dwarfs, or nearby degenerated below - the - main-sequence black dwarfs. For answering this question the parallax survey conducted by Murray at the SGP on plates obtained with the new Siding Spring Schmidt telescope is of paramount importance. In this survey Murray (New Problems in Astrometry, IAU Symp. No. 61) hopes to obtain an accuracy of 0."01, implying that it will be complete up to a distance of say 30 pc from the Sun.

Work is afoot, jointly with T. de Jong, on the evolution of low-mass stars which will ultimately become black dwarfs to find the expected number of black dwarfs in the solar neighbourhood.

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THE DISAPPEARANCE OF THE UNSEEN (EVAPORATING BLACK HOLES)

It has been suggested that in the very early stages of the evolution of the Universe, extremely high density fluctuations in spacetime (Misner, Thorne, Wheeler, *Gravitation*, San Francisco : Freeman, 1973) could create exceptionally low mass black holes (e.g. $M = 10^{15}$ g, $R=10^{-13}$ cm) (Hawking, *Mon. Not.* R. *astr. Soc.*,**152**, 75, 1971). In fact, the minimum size, corresponding to the Planck length $(Ghc^{-3})^{1/2} \approx 10^{-33}$ cm, would correspond to 10^{-5}g. Recently, in attempting to apply quantum field theory to gravitationally collapsed objects, Hawking has found that black holes can emit energy so that, if small enough, they can cease to exist. One interesting question with respect to these small black holes is "How does the uncertainty principle apply, especially to the region at the edge of a black hole?" However, a proper answer to such an inquiry is the application of quantum field theory, with gravitational coupling, to the vacuum region in question.

Bardeen, Carter and Hawking (*Commun. Math. Phys.*, **31**, 161, 1973) found that black holes (regardless of type-Schwarzschild, Kerr-Newman, etc...) are analogous to thermodynamic systems. Thus, they should have a temperature and should radiate even when in equilibrium. Although the physical radius of any black hole is infinite, in the sense of the length of a rod passing through it, the circumference is quite finite, as is the surface area,

$$A = 4\pi\,[2M^2 - Q^2 + 2(M^4 - J^2 - M^2Q^2)^{1/2}],$$

wherein M=mass of black hole
J =angular momentum
Q=charge

if the Kerr-Newman metric is used (Hawking, *Phys. Rev. D.*, **13**, 2, 192).

The work of Bekenstein in 1972 (J.D. Bekenstein, *Phys. Rev. D.*, **7**, 8, 1973) shows that, surprisingly, the surface area of a black hole is equivalent to entropy, and the surface gravity ($K = \frac{4\pi Rc^2 - GM}{A}$, where R is the "apparent radius" of the black hole) corresponds to the temperature. Using an information theory approach, Bekenstein showed that the surface area of the event horizon is the logarithm of the number of different configurations that could collapse to a black hole whose only quantum numbers are mass M, charge Q and angular momentum J. This, then, implies that the black hole has a temperature proportional to K and should emit energy thermally. In fact, Bekenstein established the validity of a generalized second law of thermodynamics with the implication that thermal equilibrium cannot be maintained by a black hole immersed in matter. Moreover, since Einstein's field