STAR COUNTS, LOCAL DENSITY AND K_z FORCE

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ABSTRACT

The approach by Bahcall and Soneira to the determination of galactic parameters through the use of star counts is referred to, and tests of the Bahcall-Soneira Galaxy model based on additional observational data are discussed.

The determination of the local mass density by Hill, Hilditch and Barnes through studies of A and F stars in the region of the North Galactic Pole is briefly discussed, as is a recent investigation of the problem by Bahcall.

In the determination of the galactic force K_z and the local mass density from the density distribution $\nu(z)$ and the distribution $f(W)$ of velocities at right angles to the galactic plane for a group of tracer stars, it is important to secure homogeneity of the tracer group. This has led Hill, Hilditch and Barnes in a continuation of their investigation to use photoelectric uvby photometry to segregate homogeneous groups of F stars. A similar approach is followed by Danish astronomers, whose work is briefly described.

STAR COUNTS, THE BAHCALL-SONEIRA GALAXY MODEL, TESTS OF THE MODEL

During the last few years star counts based on determinations of magnitudes in selected areas reaching to magnitudes 22^m-23^m have become an important tool in galactic research (cf. Kron (1978), Tyson and Jarvis (1979), Peterson et al. (1979) and Kron (1980)). Automated methods for evaluation of deep photographic plates have been developed and used to determine magnitudes for large numbers of faint stars. Fields in high and intermediate galactic latitudes, where interstellar absorption presents no great problems, have been studied, and here methods for distinguishing faint images of galactic stars and galaxies have been developed so that star counts to magnitude $B = 22\overset{m}{.}5$ are not appreciably affected by misclassification of galaxy images. This is a significant extension beyond the 18^m limit of the classical star counts.

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Guided by results concerning light distribution in external galaxies and by a large amount of available information regarding density distribution and luminosity function in our own Galaxy, Bahcall and Soneira (1980) have proposed a relatively simple two-component Galaxy model consisting of an axisymmetric, flattened disc and a spheroid, in their standard model assumed to have the three axes equal. For the disc and the spheroid, fairly simple density-distribution laws and luminosity functions are assumed, the choices being guided by the observational data just referred to. The number of free parameters in the density-distribution laws and luminosity functions is fairly small. They are adjusted so that agreement between predictions of the model and the results of the star counts is achieved as far as possible.

It is clearly important to test the predictions of the Galaxy model with data other than star counts. Kron (1978) has determined the colour-index distribution for stars in the selected area SA57 ($b=86^{\circ}$) for stars in the V-magnitude range $19^{m}_{\cdot}75$ to $22^{m}_{\cdot}0$, and found a bimodal distribution with well-separated maxima near B-V = $0^{m}_{\cdot}5$ and B-V = $1^{m}_{\cdot}5$. The distribution predicted from the Bahcall-Soneira Galaxy model agrees very well with the observed in this case. It is clear from the model prediction that the maximum at B-V = $0^{m}_{\cdot}5$ is contributed mainly by spheroid stars, while the maximum at B-V = $1^{m}_{\cdot}5$ comes from red main-sequence disc stars. Recent, as yet unpublished, results by Kron on star counts and colour-index distribution in selected areas at lower galactic latitudes do not agree as well with the predictions (Kron, personal communication).

In a paper on the significance of deep star counts for models of the Galaxy Gilmore (1981) has considered proposed Galaxy models, including the Bahcall-Soneira model, and the comparison of their predictions with observation. In particular, Gilmore discusses the question of the luminosity function for the spheroid component. In the Bahcall-Soneira model the spheroid luminosity function is put equal to the assumed disc luminosity function times a factor which is taken to be 1/800. The choice of this factor is based on a determination by Schmidt (1975) of the local density of spheroid stars from a study of local high-velocity stars with spheroid-star (i.e. halo-star) kinematics. Since the disc stars are mainly Population I stars, while the spheroid stars are extreme Population II stars, there are arguments for a different choice of luminosity function. The question of luminosity function of spheroid stars is further discussed by Bahcall, Schmidt and Soneira (1983).

In an extensive investigation Gilmore and Reid (1983) have determined the density distribution in the direction of the South Galactic Pole for a number of groups of main-sequence stars, divided according to absolute magnitude. The basic material consists of magnitudes V and colour indices V-I for a complete sample of 12500 stars brighter than I = 18^{m} in an area of 18.24 square degrees towards the South Galactic Pole. The chosen procedure for determination of individual distances depends on the assumption that the stars are on the ZAMS, so that a previously established calibration of absolute magnitude M_V versus V-I can be used. A relatively small dependence of M_V upon metal content is taken summarily into account.

As a result a two-dimensional array can be constructed that gives the number of stars in bins defined by limits in log z and M_V , the log z range covered extending from 2.05 to 3.85, while the range of M_V is from $3^m\!.5$ to $12^m\!.5$.

Among the results obtained is a determination of the luminosity function at a distance z from the galactic plane of about z = 1000 pc. Here the absolute-magnitude range from 3.5 to 8 is well covered, and it is shown that the luminosity function in this range does not differ significantly from that valid near the galactic plane. Since the relative proportion of Population II is undoubtedly higher at z = 1000 pc than in the plane, this suggests that there is no great difference between the luminosity functions for Population I and Population II in the absolute-magnitude range in question.

Using the data for the groups with M_V in the ranges 4-5 and 5-6, the density distribution is determined out to z = 4000 pc and 3000 pc respectively. The authors conclude that there is, in addition to the standard disc with a scale height of 300 pc, a "thick disc" with a scale height of about 1350 pc, the latter locally comprising about 2 per cent of the stars. This result differs markedly from that of other investigations, and in particular it disagrees with the assumptions of the Bahcall-Soneira Galaxy model. Further studies are desirable. The authors have planned continued investigations of the faint stars that are indicators of the thick disc, through determination of further indices to strengthen the absolute-magnitude determinations (Gilmore, personal communication).

With regard to the assumption that the ZAMS absolute magnitude, as indicated by V-I, can be adopted for the stars in the important M_V magnitude range 4-5, some further information is already available. We note that the "thick-disc" stars must presumably be of Population II. Now E.H. Olsen (1983), from a photoelectric uvby survey of all A5-GO stars in the Henry Draper catalogue which are brighter than $V=8^m\!.3$, has established an unbiased list of Population II stars, selected according to metal content as determined from the uvby photometry (cf. the last section of this contribution). The stars are practically all within 100 pc, and the list is complete to about 40 pc. For stars in the colour-index range (b-y) $0^m\!.29$-$0^m\!.39$, which corresponds to the ZAMS M_V range 4-5, E.H. Olsen (personal communication) has determined individual M_V- values. In addition to ZAMS stars the sample of about 400 stars contains a quite substantial number of evolved stars including subgiants, and the range of M_V for given colour index is well over one magnitude. Taking this effect into account for the Gilmore-Reid stars would influence the computed run of density with distance from the galactic plane.

Referring again to work discussed in the last section, the importance of forthcoming material of space velocities for the stars in E.H. Olsen's list of Population II stars should be mentioned. The sample is large enough for a fair determination of $\sigma(W)$, the r.m.s. velocity at right angles to the galactic plane, as a function of metal content for the stars of intermediate Population II, and an analysis will show whether indeed a fraction of all stars (in the absolute magnitude range considered) as high as 2 per cent has $\sigma(W)$-values large enough for the explanation of the "thick disc" feature.

In discussing tests of galactic models, in particular with regard to the spheroid component, we shall turn to two investigations which are based on identification of red giants of the spheroid population with the help of observational methods particularly developed for the purpose.

H.E. Bond (1980) has carried out a survey of extremely metal-deficient red giants using search on objective-prism plates followed by photoelectric uvby photometry. One objective-prism survey (Bond 1970) covers about 4000 square degrees of the northern hemisphere, with limiting B magnitude 10^m-$10^m.5$. A deeper survey, to B~$11^m.5$, covers 2300 square degrees near the North Galactic Pole and 2200 square degrees near the South Galactic Pole. These surveys are believed to be essentially complete for red giants with [Fe/H] $\leq$ -1.5 to -1.8. The selected sample of red giants thus has a metal content similar to that of member stars of the globular cluster M92. Next, photoelectric uvby photometry was carried out and used to determine individual values of [Fe/H], using the m_1-index, and further to isolate red giants, with (b-y) > $0^m.42$ and more luminous than $M_V \sim 2^m$ according to the c_1-index. Finally radial velocities were obtained for about half of the selected stars, and it was found that although selected without kinematic bias essentially all of the stars have halo-type motions. It is clear that the observational material just described is of considerable importance in tests of any galactic model with regard to its predictions concerning red giants in the spheroid population within distances 1000-2000 pc from the Sun.

A study by K.U. Ratnatunga (1982) aims at investigation of extremely metal-deficient K giants out to much larger distances and is therefore concerned with much fainter stars, to about V = 17^m. In a preliminary survey an area of 2.8 square degrees in SA141 close to the South Galactic Pole was investigated. Stars in the magnitude range 13^m<V<16^m and colour index range $0^m.9$<(B-V)<$1^m.4$ were selected. The subsequent procedure for finding metal-deficient giant K stars used low-resolution spectrophotometric observations for the determination of the strength of the MgH and Mg b feature around 5100 Å, which according to Clark and McClure is a good discriminant when the aim is to separate metal-deficient K giants from disc dwarfs. The preliminary survey of 2.8 square degrees showed that out of 126 stars in the V-magnitude range 13^m to 16^m and the B-V colour-index range $0^m.9$-$1^m.4$ a total of 23 were metal-deficient halo giants, and that of this sample 6 stars had distances larger than 10 kpc, while only 1 star was at a distance >20 kpc.

On the basis of these findings preparations have been made for an extensive survey to limiting magnitude V=$17^m.5$ in 5 fields at high galactic latitude, each covering 36 square degrees. It is expected that the required luminosity discrimination can be carried out using objective-prism Schmidt telescope plates with a dispersion of 900 Å per mm at Hγ.

It is clear that surveys of this type could contribute data of great value in the study of the properties of the spheroid component.

LOCAL DENSITY AND K_z FORCE

Oort (1965) has reviewed the problems in connection with the determination of the galactic K_z force and the local density from observational data for selected tracer groups of stars on the density distribution function $\nu(z)$ and the distribution function $f(W)$ of the space velocity component at right angles to the galactic plane, as determined for stars near the plane. It is essential that the tracer groups should be homogeneous so that the characteristics of the member stars do not vary with distance from the plane. King (1983) has emphasized this point and concluded that main-sequence stars of spectral classes F and G are much more suitable as tracer groups for the determination of the K_z force than either A stars or giant K stars.

Hill, Hilditch and Barnes (1979) have carried out a determination of the local density ρ_o, based on radial-velocity and photometric data for A and F stars. The results for F stars are of particular interest. A theoretical model due to Camm (1950, 1952) was used in deriving ρ_o. The density distribution $\nu(z)$ for the F stars for $z>100$ pc resulted from a revision of the analysis by Upgren (1962, 1963) of the Slettebak-Stock (1959) catalogue of spectral classes for stars in a North Galactic Pole region. Available data were used for a determination of the velocity dispersion $\sigma(W)$ near the galactic plane. Here the material concerning the intermediate-Population-II component among the late-type F stars was weak at the time, and it is of interest to note that quite adequate information on this point will soon be available (cf. the last section of this paper). Hill, Hilditch and Barnes (1979) emphasize the advantages that would be gained if the determination of $\nu(z)$ for F stars were based on uvbyβ photometry rather than on fairly crude spectral classification, and mention that they have embarked on an observational program of this type for stars within 15° of the North Galactic Pole. Their conclusion in the 1979 paper is that $\rho_o=0.14\ M_\odot\ pc^{-3}$, while they derive a value of the local density due to known matter in the solar neighbourhood equal to $0.108\ M_\odot\ pc^{-3}$. Thus their derived value for the "missing mass" is lower than that found in previous investigations, being reduced to $0.03\ M_\odot\ pc^{-3}$.

Bahcall (1984) has undertaken a broad-based discussion of the determination of the total amount of matter near the Sun. The combined Poisson-Boltzmann equation for the gravitational potential as a function of z is solved for Galaxy models composed of a number of isothermal components, the properties of the stellar components being assumed according to information on disc luminosity function and velocity dispersion $\sigma(W)$, cf. particularly Wielen (1974). The calculated potential is used to fit the distribution function $\nu(z)$ of F stars reported by Hill, Hilditch and Barnes (1979), by varying ρ_o as a parameter. As in previous determinations, the result depends on the assumptions made concerning the velocity dispersion $\sigma(W)$ for the "missing mass". For the preferred hypothesis Bahcall

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derives ρ_o =0.185 $M_\odot$ pc^{-3}. He concludes that the "missing mass" amounts to about one-half of the total mass, and further that this "missing mass" must be largely concentrated to the galactic disc. Alternative models are discussed, but the results obtained do not change the main conclusions.

Further discussions in which improved determinations of $\nu(z)$ and $\sigma(W)$ for main-sequence F and G stars (cf. above, and also the following section) are utilized will clearly be of importance.

THREE uvbyβ SURVEYS AND THEIR ROLE IN CONNECTION WITH THE K_z PROBLEM

E.H. Olsen (1983) has carried out an all-sky uvby survey of nearly all Henry Draper stars of types A5 to G0 and brighter than visual magnitude $8^m.3$. For about 2000 of the most metal-weak stars found, additional uvby and Hβ photometry has been obtained. The resulting catalogue presents the results of 27096 uvby and 7273 β measurements of 14816 stars.

A list of stars of intermediate Population II, as defined through the metal-content criterion $0^m.045<\delta m_1(b-y)<0^m.080$, was established on the basis of the catalogue. It contains about 600 stars forming a complete, magnitude-limited, kinematically unbiased sample of F stars belonging to intermediate Population II. An examination of the sample has fully confirmed a previous conclusion based on a much smaller sample, namely, that there is a sharp limit in the (b-y)-distribution corresponding to a turn-up at $(b-y)=0^m.29$. This shows that the members of the group of stars defined through the metal-content criterion are practically all old stars - older than about 10×10^9 years. The cut-off in the program-star selection at Harvard spectral class G0 corresponds to $(b-y)\sim0^m.40$, and the ZAMS visual absolute-magnitude range of the sample is therefore $4^m.0-5^m.0$.

J. Andersen and Mayor have undertaken to determine radial velocities for the stars on the intermediate Population II list. The observations, made with the Coravel radial-velocity instrument, have been completed, and a catalogue can be expected to be ready fairly soon (J. Andersen, personal communication). For most of the stars three Coravel determinations will be available, so that spectroscopic binaries can be segregated. Combined with proper motions and photometric distances derived from the uvbyβ photometry, the radial velocity will yield space velocities for the great majority of the 600 stars of the list mentioned, and consequently the correlations between age, chemical composition and kinematics can then be analyzed on the basis of information from an adequate sample.

With regard to the kinematics of F stars of Population I, in particular determination of $\sigma(W)$, reference is made to an investigation by Dennis (1966) which yielded $\sigma(W)$ as a function of stellar age, as derived from uvby observations of stars brighter than $V=6^m.5$. A similar investigation of a somewhat larger sample, also to $V=6^m.5$, by E.H. Olsen has given results close to those derived by Dennis (E.H. Olsen, personal communication). J. Andersen and B. Nordström have started observations on a radial-velocity program comprising a much larger sample of Population-I F stars drawn from E.H. Olsen's catalogue of 14816 stars. Ultimately this program should yield excellent information on the kinematics, in particular on $\sigma(W)$, for very homogeneous groups of stars selected on the basis of uvbyβ photometry, and thus contribute to K_z-force determinations.

J. Knude (personal communication) is obtaining photoelectric uvbyβ for A5-G0 stars within 20° of the North Galactic Pole. A list of 5500 A5-F0 program stars, complete to B about $11^m.5$, has been put at disposal by T. Oja. The spectral classes determined by Oja are from plates taken with a Schmidt telescope at the Uppsala-Kvistaberg Observatory for the purposes of a wider-scope spectrophotometric program for North Galactic Cap stars. J. Knude has carried out one-half of the photometric observations and expects that the program will be completed in 1984. Of the various applications of the resulting uvbyβ photometry the following is of importance in the context of the present article, namely, the derivation of very satisfactory distribution functions $\nu(z)$ for selected homogeneous groups of Population-I F stars out to distances of 500 pc.

T.B. Andersen (personal communication) has carried out photoelectric uvbyβ photometry in an area of 40 square degrees in the South Galactic Cap. The program consists of all stars brighter than $V=15^m.2$ and with colour index $(U-V)<0^m.60$. The selection of the program stars was made using Palomar Schmidt-telescope plates taken by B. Strömgren, these plates showing an ultraviolet-yellow image pair for each star. The evaluation of the plates was carried out by T.B. Andersen, who had the opportunity to use COSMOS at the Royal Observatory Edinburgh, with a program developed at ROE that was particularly suited to the purpose of the selection of the program stars. A pilot project by Crawford et al. (1979) showed that the selection of program stars to 15^m according to (U-V) leads to lists that contain well over 60 per cent Population II stars, a conclusion that was confirmed by T.B. Andersen's photometric results.

T.B. Andersen's project will be continued through further observations in the North Galactic Cap. It is of interest, however, to compare the results already obtained, and which pertain to stars out to distances between 1000 pc and 2000 pc, with the results found by E.H. Olsen for stars within 100 pc. The following table shows the distribution of the metal index δm_1 (b-y) for two samples, both with (b-y)-limits $0^m.29$-$0^m.39$ and δc_1 $(b-y)<0^m.10$, the E.H. Olsen sample (3949 stars) being complete to $V=8^m.2$, the T.B. Andersen sample limited to the V-magnitude range $14^m.0$-$15^m.0$ (114 stars). The material was kindly put at disposal by T.B. Andersen and E.H. Olsen prior to publication.

δm_1(b-y) unit $0^m.001$	[Fe/H]	Percentage of stars, EHO	Percentage of stars, TBA	Ratio TBA/EHO
-15 to 23	0.0	44 %	6.1 %	0.14
24 to 44	-0.2	45	26	0.58
45 to 80	-0.6	10.6	59	5.6
>80	<-0.9	0.23	8.8	38

In further work a more refined comparison procedure will be in order. However, the present "coarse analysis" clearly shows that the star density drop from the plane to volumes located somewhat beyond 1000 pc is a steeply varying function of the metal content. This fact should be of importance in future discussions of the K_z force problem, particularly when the aim is to determine K_z to larger distances z, using selected groups of Population-II stars as tracer samples.

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