A Search for F Stars of Intermediate Population II Within 100 Parsecs

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The class of stars of intermediate population II is defined through the chemical composition of the stars. A star belongs to this class if its relative heavy-element content Z is between one-fourth and one-tenth of the Z-value for Hyades stars. This means that the range in question is from Z = 0.008 to Z = 0.003, so that Z = 0.005 is a typical value.

For the great majority of population I stars the relative heavy-element contents Z lie between 0.015 and 0.035. The Z-value for the Sun is fairly close the lower limit. On the other hand, halo stars and members of most globular clusters—i.e. extreme population II stars—have Z-values that are down from the Hyades value by factors greater than 10, generally between 10 and 200. It may be noted, however, that some globular clusters, e.g. 47 Tucanae, have member star Z-values that place them in intermediate population II.

Professor Bengt Strömgren, *President of the ESO Council, needs little introduction to the readers of the* Messenger. *There are few astronomical fields to which he has not contributed and his name is attached to subjects as different as envelopes of ionized hydrogen around hot stars and high-precision photometry. The Strömgren four-colour photometric system allows an accurate determination of luminosities and ages of many types of stars. The system is particularly well suited for the large-scale investigation of the evolution of our galaxy, the Milky Way. The massive observational programme of Professor Strömgren and his collaborators in Copenhagen is a rarely seen combination of quantity and quality, already leading towards a much better understanding of the solar neighbourhood and the continued interaction between the interstellar matter and the stars.*

The limits for the Z-range defining intermediate population II have been chosen according to practical considerations. On the one hand, samples of intermediate population II stars obtained through observations should contain at most a very small fraction of stars that really belong to population I or extreme population II, and are "scattered" into the sample through observational error, and furthermore it is desirable that intermediate population II stars as defined form a fairly homogeneous group. These considerations tend to force the choice of a fairly narrow Z-range. On the other hand, it is undesirable to reduce the size of the sample so much that stars are excluded which are actually fairly similar to the typical sample star. The chosen limits seem to be adequate, and in particular a widening of the Z-range from 0.008–0.003 to, for example, 0.010–0.002 would not increase the size of the sample very much.

The task of picking out metal-poor stars with relative heavy-element contents falling in the range characteristic of intermediate population II is not a very simple one. True, through quantitative spectral analysis based on high-dispersion spectra it can be determined whether a star belongs to this class or not. However, such analysis requires much telescope time per star and it has not proved feasible to investigate large numbers of stars in this way. On the other hand, there is a good deal of experience showing that stars of intermediate population II cannot be reliably picked out through routine spectral classification based on objective-prism spectra, even when such fine spectra are used as are obtainable with the Curtis Schmidt telescope on Cerro Tololo.

Pioneer work in 1954 by Nancy Roman showed that F stars of extreme population II can be identified on the basis of their ultraviolet excess determined through photoelectric UBV photometry. This method lends itself to survey work as the required telescope time per star examined is relatively short. It was subsequently found that the same is true for *unevolved* F stars of intermediate population II, but not for the equally important type of *evolved* intermediate population II F stars, which lie $0^m.5$–$1^m.5$ above the zero-age main-sequence (ZAMS). The reason is that the chemical-composition effect on the U-magnitude is partly compensated by an evolutionary effect, connected with the fact that the evolved stars have lower atmospheric gravity.

However, some years later it was shown that F stars of intermediate population II can be reliably picked out through photoelectric four-colour observations in the uvby system (B. Strömgren, *Astrophys. Norveg.* **9,** 333, 1964). In this system, intensities of intermediate-width bands at 3500 Å, 4110 Å, 4670 Å and 5470 Å are observed.

The three intensity ratios measured permit determination, for F stars, of three parameters, namely effective temperature, absolute magnitude (or atmospheric gravity), and relative metal content. In other words, it is here possible to separate the effects of chemical composition and evolutionary change. This works for unreddened stars. For reddened stars yet another index, the β-index which indicates the strength of the Balmer-line Hβ, must be measured. Then the degree of reddening can be determined, and the method works again.

Recently B. Grønbech and E.H. Olsen have published a catalogue of photoelectric uvby photometry for 2,771 bright O- to G0-type stars south of declination +10° (*Astron. Astrophys. Suppl.*, Vol. **25,** No. 2, 1976). The observations were made with a four-channel spectrograph-photometer attached to the Danish 50 cm reflector on Cerro La Silla. The instrumental equipment, the observational procedure and the transformation of the observed quantities to the standard uvby system of Crawford and Barnes have been described in a publication by Grønbech *et al.* (*Astron. Astrophys. Suppl.*, Vol. **26,** No. 2, 1976). Altogether 13,958 photoelectric uvby observations of standard stars and programme stars were made during the two investigations referred to.

Together with a number of catalogues of uvby photometry, largely by D. L. Crawford and his collaborators of AURA, this new catalogue covers the entire sky, and uvby photometry is available for altogether about 5,000 O-G0-type stars brighter than $V = 6^m.5$, the magnitude limit of the Bright Star Catalogue.

Analysis shows that about three dozen of the 5,000 stars in question are F stars of intermediate population II, i.e. a very small fraction. However, it must be remembered in this connection that among the stars brighter than $V = 6^m.5$ there is not a single F star of extreme population II. Also, if the comparison is made with main-sequence F stars of the same colour range it turns out that the intermediate population II stars form about 7 per cent of the stars.

Although the sample of F stars of intermediate population II brighter than V = 6^{m}.5 is small, it has proved large enough for a preliminary analysis of the space velocities of the sample stars to show that the population in question is intermediate between population I and extreme population II with regard to kinematics, also. In particular, the average value taken without regard to the sign of the space velocity component at right angles to the galactic plane is larger than for population I stars, but a good deal smaller than for extreme population II stars. This suggests that stars of intermediate population II were formed during an epoch range when the Galaxy had developed a flattened disc.

Analysis of material for stars brighter than V = 6^{m}.5 has shown that the stars of intermediate population II have a distribution in the Hertzsprung-Russell diagram that is sharply limited on the high-temperature side, at a colour index b–y just under 0^{m}.30, corresponding to spectral class F5. This indicates that the stars of intermediate population II all have ages not very much smaller than the age of our galaxy.

The small sample of F stars of intermediate population II brighter than V = 6^{m}.5 has proved useful for calibrations of the metal-content index m_1 derived from uvby photometry. Such calibrations, which make possible the derivation of the relative iron content and the Z-value from measured values of m, have recently been carried out with improved accuracy by D.L. Crawford and C. Perry who utilized the available material based on quantitative spectral analysis using high-dispersion spectra, and by P.E. Nissen who determined relative iron contents trough narrow-band photoelectric photometry.

It is clear from the results just referred to that more extensive investigations of F stars of intermediate population II can yield material that will be valuable in studies of the early phases of evolution of our galaxy, in particular for investigations pertaining to the epoch when stars first began to be formed in large numbers in the galactic disc.

With this in view, plans were developed for a search for F stars of intermediate population II brighter than V = 8^{m}.3. E.H. Olsen worked out a list of programme stars for which photoelectric uvby photometry was to be carried out with the Danish 50 cm reflector on Cerro La Silla. The list included all stars in the Henry Draper catalogue brighter than V = 8^{m}.3, in the spectral range A5-G0, and south of declination +6°. Stars in the Catalogue of Bright Stars that had already been observed were excluded, and there remained altogether about 7,000 stars.

It is intended to extend the work to the northern hemisphere, once the southern-hemisphere programme has been completed. E.H. Olsen has set up a corresponding list of programme stars, and the total number of stars to be observed in both hemispheres is 13,307.

During 20 nights in August and September 1976, E.H. Olsen has obtained photoelectric uvby photometry with the Danish 50 cm reflector on Cerro La Silla for 3,600 programme stars. This covers about one-fourth of the programme for the entire sky. It is hoped that the remaining half of the southern-hemisphere observations can be completed in March and April 1977.

It should be noted that the great majority of the programme stars have only been observed once. However, the mean error of 1 observation of a programme star is ±0^{m}.005, ±0^{m}.007 and ±0^{m}.008 for b–y, m_1, and c_1, respectively, and the accuracy obtained with these observations is therefore sufficient for the establishment of an intermediate population II "candidate list" consisting of, for this one-quarter of the whole programme, a few hundred stars. Two additional observations will be obtained for stars of the "candidate list". Observations of the index β will also be obtained for the stars of the "candidate list" in order that corrections for interstellar reddening can be made, although it is expected that these will generally be small, since the great majority of the stars in this list are located within 100 parsecs. In this way a final list of intermediate population II stars will be set up as a result of the search.

The August and September 1976 observations have been reduced by the observer, and he has derived a catalogue of b–y, m_1 and c_1 in the Crawford-Barnes standard system for 3,600 stars. E.H. Olsen and the author of this article have found it worthwhile to carry out a preliminary analysis of the data even at this early stage in order to extract information pertaining to intermediate population II stars.

There appear to be somewhat over one hundred intermediate population II stars in the relevant one-fourth of the sky. We have made a somewhat restricted list of such stars, limiting ourselves to the Δm_1 range (measuring metal deficiency relative to the Hyades) 0^{m}.050 to 0^{m}.069, corresponding to Z between 0.007 and 0.004. Furthermore, we excluded stars with distances larger than 80 parsecs. This was done to counteract the effect of having at this stage only one uvby observation at disposal, and no β-index observations. There resulted a sample of 71 stars, for which the distribution of the b–y colour-index values is shown in the following table:

b–y	Number of stars
0^{m}.25–0^{m}.27	0
0 . 27–0 . 29	1
0 . 29–0 . 31	9
0 . 31–0 . 33	22
0 . 33–0 . 35	14
0 . 35–0 . 37	12
0 . 37–0 . 39	11
> 0 . 39	2

It is seen that the phenomenon of the sudden appearance of the intermediate population II stars near b–y = 0^{m}.30 is confirmed. The distribution of the stars in the (b–y)–c_1 diagram, which corresponds quite closely to the distribution in the Hertzsprung-Russell diagram, shows a well-defined ZAMS distribution and a "turn-up" near b–y = 0^{m}.30, and also a subgiant branch of evolved stars with absolute magnitudes between 3^{m} and 4^{m}. A preliminary analysis of these data, based on as yet unpublished model-atmosphere results by R. Bell and B. Gustafsson, and computed isochrones for stars with Z = 0.004 and Z = 0.01, respectively, by P.M. Hejlesen lead to the result that the stars in question have ages not far from 10 billion years. However, a determination of the age range has to wait until the expected much more complete material is at hand.

There is some hope that the entire search can be completed before the end of 1978. Plans for determinations of proper motions and radial velocities for the stars of the finally established intermediate population II list are now being considered. The aim is to obtain location in the Hertzsprung-Russell diagram, individual values of relative heavy-element content Z, mass, age, as well as space velocities for an unbiased sample of several hundred stars of intermediate population II.

Finally it should be mentioned that the photometric material obtained for large numbers of population I stars will also be of value, and that this material, too, should be supplemented with material on proper motions and radial velocities.

Investigation of F stars of intermediate population II within 100 parsecs is clearly only a first step. Studies pertaining to greater distances in the direction of the galactic poles form a logical further step, and such studies are under way. Reference is made in this connection to the article by Adriaan Blaauw in number 5 (June 1976) of the *Messenger*. A goal for the future is the exploration of the region of the central bulge of our galaxy.