(C) THE GALACTIC HALO

The objects from which the structure of the galactic halo may be derived by optical means are the extreme population II objects such as RR Lyrae variables with periods longer than 0·4 days, the sub-dwarfs, globular clusters, stars similar to those found in globular clusters such as the bright red giants, and the blue stars found in the galactic polar regions. The long-period variables with periods shorter than 200 days and the ordinary high-velocity stars are now regarded as belonging to an intermediate population II, somewhat younger than the halo population II proper.

New important information on the halo of our Galaxy and of some other galaxies has in recent years been obtained from the radio-astronomical observations. As the optical and the radio approaches are quite different they are discussed separately below.

(1) *Optical work*

The Palomar-Groningen variable star survey

From the Groningen conference emerged the programme for finding the general distribution of the variable stars in the galactic halo [1]. Three fields have been chosen at the longitude of the galactic centre and at various latitudes and one in Cygnus. An important criterion for the selection of these regions was uniformity of the absorption in the fields if any absorption at all. From the first three fields we should get information on the density distribution in a meridian plane of the galactic system through the sun and the centre, and from the fourth field data on the distribution in a plane perpendicular to this meridian plane at about the same distance from the galactic centre as that of the sun.

l	b
$327^\circ.5$	$+28^\circ$
331·0	+12
327·5	−12
48·0	+10

Dr Plaut visited the Mount Wilson and Palomar observatories in 1956 and obtained of each field 100 photographic plates and twenty photovisual ones, using the 48-inch Palomar Schmidt. The size of the regions to be investigated is $6^\circ.6 \times 6^\circ.6$. The exposures are such that the plate limit is below the 20th photographic magnitude, and the survey aims to completeness down to 17·5 median magnitude, corrected for absorption.

Plates have also been taken by Dr Plaut for the transfer of the photometric system from the Selected Areas observed by Baum to the regions in question. It is not yet known if this photographic transfer will meet all the requirements. Eventually, photo-electric sequences in the fields themselves will be desirable.

It was estimated already during the Groningen conference that the work involved in the finding of the variables and in the reductions would be considerable; the estimate was about one man full time for about six years. Since then an effort has been made to reduce the time required for finding the variables, and an electronic device has been developed at the Kapteyn Laboratory by Borgman in which the blinking is made semi-automatically. A television screen shows the difference in the brightness of the stars of the two plates compared. A difference in brightness of a star shows as a light or dark spot on the screen. Detection of the variables thus becomes easier and more variables with small amplitudes will be found than in the traditional blinking procedure. Preliminary tests indicate that the semi-automatic method is indeed more efficient than the visual method. The regular scanning for the variables will probably have started at the end of 1957.

It thus seems that this programme, which was initiated four years ago, will proceed as it was hoped, and may produce valuable information on the short-period variables in the first place, and later also on the distribution of the long-period variables. For this latter purpose plates are still being taken. Addition of a fifth field in the galactic polar region is contemplated.

It was emphasized during the conference that it would be extremely valuable to get accurate photo-electric colours for the RR Lyrae variables which will be discovered in this survey. As the stars in question will be very faint the problem will be a difficult one, which only can be tackled by few observatories.

Other variable star surveys

Other surveys of variable stars which may add information on the galactic halo are in progress at several observatories, for instance at Leiden, Stalinabad, Sonneberg, Bamberg, Odessa and Moscow. The magnitude limits of these surveys are generally brighter than in the case of the Palomar-Groningen survey, but they cover larger areas. All unstudied variables brighter than 12th magnitude at maximum are investigated at Stalinabad. New variable stars brighter than 12 to 13th magnitude are being searched at Bamberg. The Soviet observatories are proceeding with a study of variables down to the 16th and 17th magnitude, particularly in the northern Selected Areas. An extension of this programme is planned within four or five years, as soon as the new 104-inch reflector of the Crimean Observatory and the 40-inch Schmidt telescope of Burakan Observatory come into operation.

Dr Kurkarkin in this connexion repeated the offer, already made at the Groningen conference, that the Soviet astronomers are ready to co-operate in measuring and investigating plates from observatories which do not find time to evaluate the plates themselves.

Search for faint blue stars

Following another recommendation made at the Groningen conference, the Tonantzintla Observatory is engaged in a search in the galactic polar caps for faint blue stars of the type discovered by Zwicky and Humason. With the Schmidt telescope three exposures are made on each plate (Kodak 103a-D) using successively ultra-violet, blue, and yellow filters. There are thus three images of each star, exposed in such a way that their densities are the same for a star of spectral class A5. By this technique it is easy to pick out the blue stars.

The limiting photographic magnitude of the present survey is about 17. Approximately 1360 square degrees had been covered in the northern polar cap up to the time of the conference, in which about 850 new blue stars were found. If we add to these the similar stars discovered by Zwicky, Humason and Luyten, which number about 400, we have nearly one such blue star per square degree. A similar survey is in progress in the southern polar cap, and in co-operation with Dr Luyten similar work is planned to the 19th photographic magnitude in some specific Selected Areas by means of the Palomar Schmidt.

The finding list of the blue stars in the northern polar cap has been published [2] and the list of objects in the southern cap will probably be ready by the end of 1957. By means of these finding lists the objects may be identified by other observers for photo-electric photometry and for slit spectroscopy.

The blue stars discovered at Tonantzintla have been plotted together with the similar stars previously known. The resulting apparent distribution on the sky shows some irregularities, but most of these may be due to the inclusion of the stars found by Zwicky, Humason, and Luyten. Some of these do not fulfil the Tonantzintla criterion for selection; when they are disregarded a relatively smooth distribution is obtained. No detailed statistics have been made as yet, but it is obvious that the number of blue stars in the polar caps increases rapidly with decreasing apparent brightness.

Some of the extremely blue stars are perhaps variables of the SS Cygni type. In order to establish this more plates will be taken.

(2) *Radio observations*

After his discovery of the halo of M 31, Baldwin [3] four years ago made a galactic survey at 3·7 m. He found that the radiation is not homogeneously distributed over the sky but markedly concentrated around the direction of the galactic centre. This was also found in the surveys of Bolton and Westfold [4] at 3 m, and in those of Dröge and Priester [5] at 1·5 m. These observations prove the galactic origin of most of the radiation.

Recent surveys by Mills [6] at 3·5 m also show the halo component very well, but it is somewhat difficult to separate it from the extra-galactic component. According to Mills the halo component has an angular width between half-brightness levels of 60° to 70°, which corresponds to 10 kpc in the region of the galactic centre. Baldwin has computed a number of models fitting his observations. They have the form of an almost spherical sub-system (axial ratio $> 0{\cdot}7$) with uniform emission per unit volume and a radius of about 14 kpc.

A survey of 21-cm profiles at high galactic latitudes was made at Kootwijk [7] in 1955. The profiles show high tops going up to 20° K at about zero radial velocity and very long wings of low intensity. The average extreme velocities of the wings are -42 and $+24$ km/sec, and there does not seem to be any correlation between the observed velocity values and the direction. Slightly more negative than positive velocities seem to be present. In some profiles recently obtained at Dwingeloo, the central maximum is much wider in velocity than the maxima observed near the galactic equator, with half-widths corrected for the band-width of the order of 30–50 km sec. The neutral hydrogen in the halo is thus in a much more turbulent state of motion than that in the galactic plane.

Although the density must be very low the continuum observations seem to indicate that the halo, owing to the large volume, contributes a fairly substantial proportion of the whole galactic mass. At 3·5 m the halo accounts for something like 90% of the continuous radiation from our Galaxy. The main difficulty for a more thorough evaluation is the superposed extra-galactic component. In principle the two components may be separated, because the halo component is spheroidal around the centre while the extra-galactic component should be spherical around the sun, but in practice the separation is very difficult.

Another possible way of evaluating the general extra-galactic contribution has recently been suggested by Shain [8]. In low frequencies the ionized hydrogen regions will be opaque and blot out all extra-galactic radiation. Hence, if we observe a distant H II region in high galactic latitude, for instance the nebula 30 Doradus at, say, 15 m, we will measure only the radiation from the gas in front of the nebula. From comparisons with nearby regions we may then evaluate the radiation from the background.

At radio-frequencies the halo of our Galaxy shows less concentration to the centre than the globular clusters and other typical halo population II objects. As early type galaxies, rich in population II, are not detected as radio emitters it seems that the radio halo is not immediately connected with population II [9]. The halo observed at radio frequencies seems to consist partly of neutral hydrogen, and partly of high energy electrons radiating according to the synchrotron mechanism as suggested by Sklovsky [10]. The general distribution, the non-thermal spectrum, and the lack of fine-structure indicate this latter mechanism.

The most complete observations of a halo outside the Galaxy are those of M 31. Baldwin [11], at 3·7 m, finds a rather smooth distribution, no central maximum and a diameter between half-intensity points of 2°.4. At 75 cm, Seeger, Westerhout, and Conway [12] find radiation out to 5° from the centre, having a very flat distribution with half-width $6° \times 3°.5$. After correcting for the known tilt of M 31 one finds a value of 3 : 1 for the ellipticity of the halo, which is quite large compared with Baldwin's estimate [3] for the galactic system. At 21 cm, van de Hulst, Raimond, and van Woerden [13] have detected neutral hydrogen out to 2°.5 from the centre on the major axis of M 31.

According to observations at Sydney, the Magellanic Clouds at 3·5 m show very little sign of a halo [6]; the whole radiation is concentrated to the central part of these systems. At 21 cm, however, an extensive halo of neutral hydrogen is observed [14]. This is contrary to the halo of our Galaxy, which is most important in the continuum.

NGC 5128 has very recently been shown by Mills and Sheridan at 3·5 m to be a very large elongated object with a major axis of 8° to 9°, much larger than the optical object, which is about 25′ in size. Here also we have a gigantic halo, but it is very flattened.

Finally, recent 21-cm observations by Heeschen of M 51 and M 81 also show the existence of large haloes of neutral hydrogen. The radio diameter of M 51 is about 2° as compared with the optical diameter of about 15′. The observations of M 81 are less certain, but a large halo is certainly indicated.

During the conference Oort expressed some doubt as to whether the

21-cm observations of other galaxies far from the central regions refer to matter in the haloes. It may well be disk matter. From the evidence of the neutral hydrogen in our Galaxy at high galactic latitude one would expect a large velocity dispersion in the haloes of other galaxies as well. This is not shown by the present observations.

References

[1] Symposium No. 1 of the I.A.U. *Co-ordination of Galactic Research*, ed. A. Blaauw (Cambridge University Press, 1955), p. 4.

[2] Iriarte, B. and Chavira, E. *Bol. Obs. Tonantzintla y Tacubaya*, no. 16, 3, 1957.

[3] Baldwin, J. E. Symposium No. 4 of the I.A.U. *Radio Astronomy*, ed. H. C. van de Hulst (Cambridge University Press, 1957), p. 233.

[4] Bolton, J. E. and Westfold, K. C. *Austr. J. Sci. Res.* A**3**, 19, 1950.

[5] Dröge, F. and Priester, W. *Z. f. Astroph.* **40**, 236, 1956.

[6] Mills, B. Y. *Austr. J. Phys.* **8**, 368, 1955.

[7] Westerhout, G. Symposium No. 4 of the I.A.U. *Radio Astronomy*, ed. H. C. van de Hulst (Cambridge University Press, 1957), p. 26.

[8] Shain, C. A. *Mt Stromlo Pre-conference on Co-ordination of Galactic Research*, p. 53, Canberra, 1957.

[9] Mills, B. Y. *Radio Frequency Radiation from External Galaxies*, Handbuch der Physik, in press.

[10] Sklovsky, I. S. *Dok. Akad. Nauk S.S.S.R.* **90**, 983, 1953.

[11] Baldwin, J. E. *Nature*, **174**, 320, 1954.

[12] Seeger, Ch. L., Westerhout, G. and Conway, R. G. *Astroph. J.* **126**, 585, 1957.

[13] Hulst, H. C. van de, Raimond, E. and Woerden, H. van. *Bull. Astr. Inst. Netherl.* **14**, 1, 1957.

[14] Kerr, F. J., Hindmann, J. V. and Robinson, B. J. *Austr. J. Phys.* **7**, 297, 1954.

(D) THE NUCLEAR REGION

The nuclear region may be explored by means of both radio and optical data. Optical methods include surveys of variable stars and various other objects, but of special interest are measurements in the far infra-red, which may provide a connexion between optical and radio observations.

(1) *Optical investigations*

Variable stars

Surveys of variable stars in three selected fields in the nuclear region were reported by Oosterhoff. The centres of the fields are

	l	b
Sgr I	329°.1	−4°.0
Sgr II	331.7	−6.6
CPD −31° 5547	329	−10