

## STAR STREAMS AND GALACTIC STRUCTURE

OLIN J. EGGEN

Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories,<sup>1</sup> Casilla 603, La Serena, Chile  
 Electronic mail: oeggen@noao.edu

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## ABSTRACT

The Solar Circle Star Stream contains three stellar groups and the HR 1614 supercluster with ages (and heavy element abundances) of 4 giga years ( $[\text{Fe}/\text{H}]=0.1$ ), 10 giga years ( $[\text{Fe}/\text{H}]\sim-0.5$ ), and 15 giga years ( $[\text{Fe}/\text{H}]\sim-1.5$ ). The velocity dispersions  $\sigma(U, W)$ , are 15 km/s at 4 giga years, 36 km/s at 10 giga years, and 75 km/s at 15 giga years. These velocity dispersions over the whole range of group velocities are  $\sigma(U, W)\sim 0.25V$  velocity. Possible effects of star streams on concepts of galactic structure are discussed and the stellar content of Stream II (the Sirius supercluster) is also reviewed. © 1996 American Astronomical Society.

## 1. INTRODUCTION

For 125 years, from its conception by W. Herschel in 1775 to the beginning of the present century, the process of deriving the solar motion assumed that the *môtus peculiares* of the stars are at random. At the turn of the century Jacob Kapteyn established a fundamental peculiarity in stellar motions and found that, instead of moving indiscriminately in all directions, as a random distribution implies, they tend to move in two favored directions. Between 1925 and 1930 Ralph Wilson and Harry Raymond, with proper motions, and Gustav Strömberg, with radial velocities, demonstrated that the situation is more complicated but for stars of intermediate space velocities the two Kapteyn streams predominate. The stellar content of star Stream I (Hyades) was discussed in Eggen (1996b) and stars in Stream II (Ursa Mayor) are reviewed in Sec. 2.

It is here assumed that most stars are born in batches and these batches evolve through three recognizable stages. The individual stars in a cluster are on isoperiodic, galactic orbits. External and internal stresses may cause small perturbations in the  $U$  (positive in the antigalactic center direction),  $V$  (positive in the direction of galactic rotation), and  $W$  (positive toward the NCP) vectors of the total space motion,  $V_{\text{TOT}}$ , which in the first instance, lead to the formation of a cluster halo (e.g., Eggen 1993a). One km/s is about a parsec in  $10^6$  yr so a 0.1 km/s perturbation in a  $10^9$  yr old cluster will spread the cluster members over a 100 pc radius. This small perturbation will be masked by observational uncertainties in the observed stellar motions so such parameters as the convergent point of the proper motions will still be obtainable with some accuracy. These greatly expanded clusters are here called superclusters and they are amenable to treatment as normal, moving clusters. As the vectors of the

space motion of individual supercluster members become more perturbed, a tube of orbits is generated with the radius of the tube, in  $(U, W)$  velocity space, determined by the size of the perturbation. Similar perturbations in the  $V$  velocity will spread the stars along the tube and this  $V$  velocity, of what will be here called a stellar group, will depend on the period of the stars that arrive at the intersection of our observational horizon with the orbit tube. Woolley (1965) found that for a  $10^9$  yr old stellar group the spread in  $V$  velocity at this intersection is only  $\pm 0.5$  km/s and for a  $10^{10}$  yr old group it is  $\pm 0.05$  km/s. Therefore clusters are recognized by their appearance, superclusters by the size and  $(U, V, W)$  distribution of the space motion and stellar groups by the value of the  $V$  velocity.

Of the four superclusters recognized in the young disk population, three (Pleiades, IC 2391, and Hyades) are on outbound ( $+U$  velocity) orbits. These three superclusters, which represent an age range from about  $10^8$  yr for IC 2391 to  $10^9$  yr for the Hyades, take part in what appears, in the solar neighborhood, to be a general galactic expansion. Individual stellar associations have been found to be expanding (e.g., Ambartsumian 1950; Blaauw 1952) but this expansion was believed to be symmetric within each association. It appears however, that the entire young disk population in the solar vicinity, that is on outward bound orbits partakes of a general expansion of some 40 km/s/kpc (Eggen 1961; Lesh 1968). This is most dramatically seen in the Pleiades supercluster where the principle components are aligned along a radius vector with the Sco-Cen association some 150 pc inside the solar circle, at the sun, and the Pleiades, the  $\alpha$  Persei cluster and the Cas-Tau association some 100–200 pc outside this circle. Using a calibration of Strömberg plus  $H\beta$  photometry based on a modulus of 5.70 mag for the Pleiades cluster, the  $U$  velocities of the supercluster stars in the Sco-Cen association are  $+5$  km/s, rising to about  $\sim 11$  km/s for the Pleiades and  $+15$  km/s for the Cas-Tau stars (Eggen 1961, 1992c). This uniform expansion has no effect on the apparent convergent point of the proper motions but the total space velocity is complicated by the presence of a variation

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TABLE 1. Members of Stream II that are not members of the Sirius supercluster.

| HD<br>FK5 | $\mu_\alpha/\mu_\delta$<br>0°0001 | $\nu/\tau$<br>0°0001 | $\frac{v}{\tau}$ | Sin $\lambda$ | $M_V$<br>PHOTO     | $V_o$             | $V_{TOT}$<br>km/sec | $\rho$<br>Comp | Obs     | Sp.T.        | HR         |
|-----------|-----------------------------------|----------------------|------------------|---------------|--------------------|-------------------|---------------------|----------------|---------|--------------|------------|
| 3546      | -2272/-2515                       | 3388/77              | 0.023            | 0.999         | +1 <sup>m</sup> 32 | 4 <sup>m</sup> 32 | 64.0                | +2.3           | -83.6   | G8 III       | 163        |
| 4502      | -999/-831                         | 1293/-126            | -0.097           | 0.997         | -0.06              | 3.97              | 39.3                | +3.0           | -23.9   | K1 IIIp      | 215        |
| 11171     | -1460/-932                        | 1727/128             | 0.074            | 0.963         | +2.95              | 4.67              | 18.0                | +3.8           | -0.9    | F2 IV        | 531        |
| 94890     | 772/-1275                         | 1487/101             | 0.068            | 0.990         | +1.12              | 4.58              | 35.0                | -15.5          | -0.2    | K1 III       | 4273       |
| 95345     | 144/-157                          | 213/13               | 0.061            | 0.736         | 0.00               | 5.50              | 12.7                | -8.6           | +6.0    | K1 III       | 4291       |
| 97603     | 1422/-1296                        | 1911/-222            | -0.116           | 0.620         | +1.00              | 2.57              | 30.1                | -23.6          | -20.0   | A4 V         | 4357       |
| 100825    | 361/-495                          | 612/23               | 0.038            | 0.997         | +1.60              | 5.20              | 15.3                | +1.2           | +5.2    | F0 V         | 4466       |
| 138716    | 3077/-2354                        | 3874/-29             | -0.008           | 0.944         | +1.05              | 4.64              | 95.9                | +28.5          | +47.7   | K1 III       | 5777       |
| 151769    | 957/-932                          | 1330/-128            | -0.096           | 0.839         | +2.96              | 4.62              | 13.5                | +7.4           | +0.2    | F5 IV-V      | 6243       |
| 185958    | 96/-136                           | 329/24               | 0.093            | 0.838         | -0.58              | 4.29              | 14.7                | +8.0           | -21.0   | G8 IIIa      | 7488       |
| 188512    | 462/-4820                         | 4821/449             | 0.093            | 0.711         | +3.15              | 3.70              | 29.6                | +20.9          | -39.8   | G8 IV        | 7602       |
| 205435    | -233/-941                         | 969/-36              | -0.037           | 0.996         | +0.79              | 4.00              | 20.1                | +1.9           | +7.2    | G5 III       | 8252       |
| 211539    | -397/599                          | 717/54               | 0.075            | 0.750         | +1.35              | 5.64              | 32.7                | +21.6          | +19V    | K0 III       | 8505       |
| 214396    | -677/-1197                        | 1367/146             | 0.107            | 0.691         | +0.05              | 5.05              | 93.8                | +67.9          | +8.2    | K2 III       | 8610       |
| 216228    | -656/1248                         | 1410/-12             | -0.008           | 0.955         | +0.57              | 3.50              | 27.0                | -8.0           | -12.4   | K0 III       | 8694       |
| 222603    | -1288/-1551                       | 1961/88              | 0.045            | 0.851         | +1.75              | 4.50              | 38.8                | +20.4          | +10.2   | A7 V         | 8984       |
| FK5 EXT   |                                   |                      |                  |               |                    |                   |                     |                |         |              |            |
| 905       | -1227/-1476                       | 1919/-4              | -0.002           | 0.999         | +2.85              | 5.70              | 33.8                | -1.8           | -29.8   | F0 IV        | 41         |
| 23319     | -878/-772                         | 1169/26              | 0.002            | 0.982         | +0.51              | 4.58              | 36.8                | +7.0           | +9.9    | K2 III       | 1143       |
| 47220     | -373/-490                         | 616/-17              | -0.028           | 0.720         | +0.34              | 6.10              | 57.5                | -40.0          | -7.6    | K1 III       | 2480       |
| 61363     | -531/-1285                        | 1388/86              | 0.062            | 0.700         | +1.50              | 5.50              | 59.3                | +42.3          | +39.8   | K0 III       | 2939       |
| 68077     | -217/-328                         | 393/-5               | -0.013           | 0.811         | +0.30              | 5.80              | 28.9                | +16.9          | +7.1    | G9 III       | 3200       |
| 82870     | 190/-595                          | 601/-64              | -0.106           | 0.719         | +0.10              | 5.42              | 45.9                | -81.9          | +12.6   | K1 III       | 3814       |
| 119476    | 538/-122                          | 549/-56              | 0.102            | 0.771         | +1.36              | 5.50              | 22.7                | -14.4          | -6 Var  | A1.5 V       | 5162       |
| 214567    | -481/-988                         | 1099/11              | 0.010            | 0.900         | 0.00               | 5.75              | 81.8                | +35.6          | -20.V   | G8 II        | 8618       |
| FK5 SUPP  |                                   |                      |                  |               |                    |                   |                     |                |         |              |            |
| 3326      | -724/-526                         | 892/74               | 0.084            | 0.797         | +2.50              | 6.05              | 27.2                | +16.4          | +13.5   | Am           | 151        |
| 7374      | -270/-255                         | 371/8                | 0.022            | 0.996         | -0.38              | 5.86              | 31.3                | +2.9           | -15.2   | B8 III       | 364        |
| 43318     | -1572/-2201                       | 2705/27              | 0.010            | 0.771         | +3.90              | 5.62              | 28.3                | -18.0          | -37.0   | F6 V         | 2233       |
| 74137     | 19/-977                           | 977/-6               | 0.006            | 0.807         | +1.25              | 4.78              | 23.5                | -13.9          | -2.0    | K0 III       | 3441       |
| 87808     | 159/-627                          | 144/-75              | -0.116           | 0.856         | -1.05              | 5.50              | 71.2                | -36.7          | +10.9   | K7 III       | 3977       |
| 132833    | 270/-226                          | 352/-11              | -0.032           | 0.994         | -1.15              | 5.50              | 35.9                | +3.9           | -14.9   | M0 III       | 5590       |
| 144206    | 585/-587                          | 827/-58              | -0.070           | 0.971         | -6.52              | 4.72              | 45.1                | -11.0          | +3.5    | B9 III       | 5982       |
| 153653    | 435/-480                          | 647/-23              | -0.036           | 0.991         | +2.04              | 6.58              | 24.9                | -3.1           | -33 Var | A5 V         | 6317       |
| 206067    | -262/-816                         | 857/-9               | -0.010           | 0.678         | +0.90              | 4.86              | 37.1                | +27.3          | -34.5   | K0 III       | 8277       |
| 218061    | -485/-389                         | 622/-14              | -0.022           | 0.626         | -0.10              | 6.08              | 81.0                | +63.2          | -15.1   | K4 III       | 8783       |
| Gliese    |                                   |                      |                  |               |                    |                   |                     |                |         |              |            |
|           | 0°001                             | 0°001                |                  |               |                    |                   |                     |                |         | HD<br>(Name) |            |
| 81.1      | -363/-340                         | 436/-26              | -0.060           | 0.970         | +3.93              | 6.42              | 67.0                | +16.3          | -6.8    | G5           | 11964      |
| 173       | -223/-207                         | 304/-13              | -0.042           | 0.961         | +10.14             | 10.34             | 16.4                | -4.5           | -7.0    | M1           | -11.916    |
| 291AB     | -68/-346                          | 353/0                | 0.000            | 0.798         | +4.45              | (5.50)            | 33.8                | -20.3          | -21.7   | G2 V         | HR3064     |
| 468       | 171/-178                          | 247/-4               | -0.017           | 0.978         | +7.46              | 9.16              | 26.2                | -5.5           | +2.7    | M0           | G63-36AB   |
| 508.2     | 518/-288                          | 592/-31              | -0.052           | 0.930         | +9.95              | 10.60             | 45.6                | -25.5          | -23.3   | M0           | +35.2439   |
| 532       | 426/-143                          | 449/13               | 0.029            | 0.824         | +8.39              | 8.92              | 29.4                | -16.6          | -44.8   | M0           | +50.2030   |
| 541.1     | 268/-231                          | 354/-15              | -0.042           | 1.000         | +4.33              | 6.46              | 44.7                | +3.4           | -14.1   | G8 V         | 125184     |
| 659       | 85/-110                           | 139/-7               | -0.050           | 0.976         | +7.33              | 8.83              | 13.5                | -2.9           | +1.6    | K8           | +54.1861/2 |
| 665.1     | 103/-76                           | 127/-13              | -0.100           | 0.696         | +4.06              | 6.60              | 27.8                | +20.0          | -14.7   | G3 V         | 156365     |
| 700.2     | 390/-600                          | 715/32               | 0.045            | 0.960         | +5.90              | 6.99              | 58.3                | +16.4          | +19.8   | K0 V         | 164922     |

in the  $V$  velocity, dictated by the requirement that the supercluster stars are isoperiodic,

$$dV/dX = -(A - B),$$

where  $X$  is the galactic radial distance from the sun and  $A$  and  $B$  are the Oort constants of galactic rotation (Woolley 1965).

The total effect of the expansion term and the rotation (isoperiodic) term on the total space motion,  $V_{TOT}$ , depends on the relative contributions of  $U$  and  $V$  to that total. The three young disk superclusters give (Eggen 1992c, 1996b):

|          | $U$<br>(at the sun) | $V$   | $V_{TOT}$           |
|----------|---------------------|-------|---------------------|
| IC 2391  | +20.8               | -15.9 | +27.4 + 0.038X km/s |
| Pleiades | +11.6               | -20.7 | +26.1 + 0.025X      |
| Hyades   | +40.4               | -16.0 | +43.5 + 0.045X      |

The apparent absence of the expansion term in the one young disk supercluster with an inbound ( $-U$ ) orbit is discussed in Sec. 2. In discussing stellar groups the presence of an expansion term is obviously not determinable but the group parallaxes will depend on the relation

$$V = A + BX.$$

The assumption that stellar motions were completely mixed plagued the solar motion search for over a century and we may be still making the same mistake. It is possible that

TABLE 2. Members of the Sirius supercluster.

| HD        | $\mu_\alpha/\mu_\delta$<br>0:0001 | $v/r$<br>0:0001 | P.V.<br>km/sec | Sin $\lambda$ | MOD   | $V_0$             | (B-V) $_0$        | Clus               | $M_V$              | Photo | Clus  | $\rho$ | Obs | Sp.T.     | HR       | Note |
|-----------|-----------------------------------|-----------------|----------------|---------------|-------|-------------------|-------------------|--------------------|--------------------|-------|-------|--------|-----|-----------|----------|------|
| FK5       |                                   |                 |                |               |       |                   |                   |                    |                    |       |       |        |     |           |          |      |
| 24160     | -663/-515                         | 689/85          | +2.0           | 0.987         | 3.76  | 4 <sup>m</sup> 19 | 0 <sup>m</sup> 95 | +0 <sup>m</sup> 43 | +0 <sup>m</sup> 50 |       | +3.0  | +2.0   |     | G8 III    | 1195     |      |
| 33111     | -941/-812                         | 1236/-130       | -1.8           | 0.903         | 2.30  | 2.73              | 0.11              | +0.43              | +0.50              |       | -8.0  | -10.0  |     | A3 III    | 1666     |      |
| 38392     | -2911/-3713                       | 4707/-334       | -1.3           | 0.954         | -0.49 | 6.17              | 0.94              | +6.66              |                    |       | -5.6  | -8.6   |     | K2 V      | 1982     | X    |
| 38393     |                                   |                 |                |               |       | 3.59              | 0.47              | +4.08              | +4.16              |       | -16.1 | -19.2  |     | F6 V      | 1983     | X    |
| 40183     | -574/-1                           | 574/-10         | -0.2           | 0.503         | 2.68  | (2.62)            | 0.02              | -0.69              |                    |       | -9.1  | -9.2   |     | A2 V      | 2088     | X    |
| 48915     | -5464/-12077                      | 13262/120       | +0.1           | 0.872         | -2.94 | -1.41             | 0.00              | +1.53              | +1.47              |       | -10.1 | -12.0  |     | A0 V      | 2491     | X    |
| 65810     | -20/-387                          | 386/36          | +1.4           | 0.838         | 4.65  | 4.33              | 0.055             | -0.12              | -0.17              |       | -4.16 | +4.9   |     | A3 V      | 3131     | X    |
| 78045     | -7/-956                           | 956/-91         | -1.7           | 0.968         | 3.00  | (4.60)            | 0.11              | +1.60              | +1.60              |       | -6.8  | -10V   |     | A5 III    | 3615     | X    |
| 78922A    | 17/-476                           | 475/-41         | -1.5           | 0.932         | 4.43  | (10.78)           | 0.875             | +6.35              | +1.17              |       | -16.5 | -12.3  |     | A6 III-IV | 3644     | X    |
| BC        |                                   |                 |                |               |       |                   |                   |                    |                    |       |       |        |     | K         |          | X    |
| 91480     | 672/394                           | 779/-15         | 0.0            | 0.461         | 1.83  | 5.15              | 0.33              | +3.32              | +3.22              |       | -15.0 | -12.0  |     | F1 V      | 4141     |      |
| 95418     | 820/342                           | 889/15          | +0.2           | 0.507         | 1.75  | 2.33              | -0.04             | +0.58              | +0.35              |       | -4.6  | -5.8   |     | A0 V      | 4295     |      |
| 102070    | 314/-297                          | 427/68          | +2.5           | 0.949         | 4.68  | 4.69              | 0.98              | +0.01              | +0.10              |       | -14.8 | -12.9  |     | G8 III    | 4514     |      |
| 103287    | 953/117                           | 960/36          | +0.4           | 0.600         | 1.95  | 2.36              | -0.02             | +0.41              | +0.31              |       | -13.5 | -11.0  |     | A0 V      | 4554     |      |
| 106591    | 1037/93                           | 1041/14         | +0.2           | 0.644         | 1.93  | 3.24              | 0.06              | +1.31              | +1.15              |       | -13.0 | -11.0  |     | A3 V      | 4660     |      |
| 112185    | 1116/-60                          | 1117/36         | +0.4           | 0.713         | 1.99  | 1.75              | -0.04             | -0.24              | --                 |       | -13.0 | -11.0  |     | Ap        | 4905     | X    |
| 116656    | 1215/-204                         | 1231/43         | +0.5           | 0.764         | 1.93  | (2.98)            | 0.00              | +1.05              | +1.13              |       | -12.0 | -11.0  |     | A1 IV     | 5054     | X    |
| 116657    | 1847/-1659                        | 2479/-173       | -1.3           | 0.987         | 0.97  | 4.92              | 0.44              | +3.95              | +2.20              |       | -8.0  | -3.0   |     | Am        | 5055     | X    |
| 134083    | 1209/-891                         | 1499/101        | +1.2           | 0.995         | 2.08  | 2.14              | -0.03             | +0.06              | +4.10              |       | -1.8  | +1.4   |     | F5 V      | 5634     | X    |
| 139006    |                                   |                 |                |               |       | 3.55              | 0.05              | +0.11              | +0.25              |       | +1.1  | +1.0   |     | A0 V      | 5793     | X    |
| 141003A   | 668/-453                          | 802/99          | +2.3           | 0.998         | 3.44  | 9.92              | 0.48              | +6.48              | +0.25              |       | -12.2 | -12.2  |     | A1 V      | 5867     | X    |
| +15.2906A |                                   |                 |                |               |       | 8.16              | 0.645             | +4.72              |                    |       | -9.9  | -12.2  |     | K3 V      | +159766A | X    |
| B         |                                   |                 |                |               |       | 10.47             | 1.12              | +7.03              |                    |       | -9.9  | -12.2  |     | A2 V      | 7025     | B    |
| 172864    | 137/-271                          | 304/-8          | -0.4           | 0.847         | 5.19  | 6.15              | 0.04              | +0.96              |                    |       | -12.2 | -12.2  |     |           |          | X    |
| FK5 EXT   |                                   |                 |                |               |       |                   |                   |                    |                    |       |       |        |     |           |          |      |
| 34109     | -166/129                          | 210/11          | +0.8           | 0.754         | 5.75  | 6.69              | 0.00              | +0.94              | +0.70              |       | -12.2 | -15.2  |     | A0 V      | 1714     |      |
| 109799    | 800/-900                          | 1204/-39        | -0.6           | 0.998         | 2.56  | 5.45              | 0.33              | +2.89              | +2.70              |       | -1.2  | -0.9   |     | F2 V      | 4803     |      |
| 110066    | 217/-61                           | 224/23          | +1.4           | 0.738         | 5.56  | 6.45              | 0.06              | +0.89              |                    |       | -12.5 | -12.6  |     | Ap        | 4816     | X    |
| 180777    | 486/-1235                         | 1312/53         | +0.7           | 0.914         | 2.16  | 5.11              | 0.31              | +2.95              | +2.85              |       | -8.0  | -5.5   |     | F2 V      | 7312     |      |
| FK5 SUP   |                                   |                 |                |               |       |                   |                   |                    |                    |       |       |        |     |           |          |      |
| 1227      | -202/-190                         | 277/-14         | -0.9           | 0.934         | 5.61  | 6.14              | 0.92              | +0.53              | +0.54              |       | +6.6  | +3.00  |     | G8 II-III | 59       |      |
| 11428     | -104/-62                          | 121/-6          | -0.9           | 0.956         | 7.46  | 5.35              | 1.30              | -2.22              | -2.00              |       | -5.4  | -7.3   |     | K1 III    | 543      |      |
| 32977     | -471/-338                         | 579/23          | +0.6           | 0.748         | 3.52  | 5.29              | 0.10              | +1.77              | +1.52              |       | -12.3 | Var    |     | A5 IV     | 1658     | X    |
| 75605     | 21/-491                           | 491/-6          | -0.2           | 0.944         | 4.39  | 5.18              | 0.86              | +0.79              | +0.99              |       | -6.1  | -7.8   |     | G5 III    | 3512     |      |
| 111397    | 260/-192                          | 323/-3          | -0.1           | 0.866         | 5.11  | 5.61              | 0.00              | +0.50              | +0.38              |       | -9.3  | -7.3   |     | A1 V      | 4865     |      |
| 140160    | 399/-310                          | 505/26          | +0.9           | 0.997         | 4.45  | 5.32              | 0.04              | +0.87              | --                 |       | +1.5  | +1.9   |     | A5p       | 5843     | X    |

TABLE 2. (continued)

| HD            | $\mu_\alpha/\mu_\delta$<br>0 <sup>h</sup> 00 <sup>m</sup> 1 | $\nu/\tau$<br>0 <sup>h</sup> 00 <sup>m</sup> 1 | P.V.<br>km/sec | Sin $\lambda$ | MOD  | $V_0$ | (B-V) <sub>0</sub> | $M_V$<br>Clus | $M_V$<br>Photo | $\rho$<br>Clus | $\rho$<br>Obs | Sp.T.  | HR                 | Note |
|---------------|-------------------------------------------------------------|------------------------------------------------|----------------|---------------|------|-------|--------------------|---------------|----------------|----------------|---------------|--------|--------------------|------|
| Gliese<br>No. | 0 <sup>h</sup> 00 <sup>m</sup> 1                            | 0 <sup>h</sup> 00 <sup>m</sup> 1               |                |               |      |       |                    |               |                |                |               |        |                    |      |
| 227           | -123/-106                                                   | 162/-3                                         | -0.2           | 0.642         | 0.96 | 6.73  | 0.81               | +5.77         |                | -11.2          | -11.7         | K0 V   | HD (Name)<br>41593 |      |
| 244           | See FK5, HD 48915                                           |                                                |                |               |      |       |                    |               |                |                |               |        |                    |      |
| 333.2         | See FK5, HD 78045                                           |                                                |                |               |      |       |                    |               |                |                |               |        |                    |      |
| 457           | 93/14                                                       | 94/2                                           | +0.2           | 0.642         | 2.14 | 10.04 | 1.28               | +7.90         |                | -14.3          | -15.0         | M0     | +59.1428           |      |
| 459           | See FK5, HD 106591                                          |                                                |                |               |      |       |                    |               |                |                |               |        |                    |      |
| 503.2         | 114/-18                                                     | 115/-1                                         | -0.1           | 0.740         | 2.01 | 6.84  | 0.60               | +4.83         |                | -12.4          | -10.1         | G1.5 V | 115043             |      |
| 509.1         | 118/-22                                                     | 120/-3                                         | -0.4           | 0.758         | 1.97 | 9.74  | 1.27               | +7.77         |                | -12.1          | -8.9          | M0 V   | +58.1441           |      |
| 9417          | 110/-2                                                      | 110/-3                                         | -0.4           | 0.701         | 1.99 | 5.85  | 0.46               | +3.86         | +3.65          | -13.3          | -12.0         | F6 V   | HR 4867            |      |
| 632           | 915/-866                                                    | 1249/-16                                       | -0.2           | 0.843         | 2.12 | 7.00  | 0.62               | +4.98         | +5.00          | -10.0          | -14V          | G3 V   | HD 150706          |      |
| 748.1         | See FK5 EXT, HD 180777                                      |                                                |                |               |      |       |                    |               |                |                |               |        |                    |      |

Notes to TABLE 2.

FK5  
28392/3  
40183  
48915  
78045  
78922AB  
112185  
116656/7  
139006  
141003  
FK5 EXT  
110066  
FK SUP  
32977  
140160  
Gliese  
9417

Gamma Lep AB, 96 arcsec separation. The cluster parallax is 0.125 arcsec and the trigonometric value is 0.128 arcsec.  
Beta Aur, eclipsing binary,  $P = 3.96d$ .  
Alpha Cha. Visual binary,  $P = 50.04y$  and  $a = 7.55$  arcsec. Companion is a white dwarf. The cluster parallax is 0.387 arcsec and the trigonometric value is 0.378 arcsec.  
Alpha Vol. Two spectra, equal components.  
Epsilon Pyx. B and C are separated by 0.3 arcsec and have nearly equal magnitude. A-BC is 18 arcsec.  
Epsilon UMa. Apcr. Light variable.  
Zeta UMa. AB separated by 14 arcsec. 116656 is a Sp.B.,  $P = 20.5d$  and equal components of 2.45 solar masses.  
Alpha CrB. Eclipsing binary,  $P = 17.4d$ . The masses are 2.6 and 0.9 solar masses and the companion has ( $M_V$ , B-V) = (5.1, 0.63 mag).  
+15°2906 is ADS 9766 with components separated by 6 arcsec and the pair is 1642 arcsec from Beta Ser AB(ADS 9778) where the components are separated by 31 arcsec.

AX CVn. Magnetic star.

Velocity range near 20 km/sec.  
Chi Ser, light variable.  $P = 1.5d$ . Magnetic star.

See Woolley et al. 1970.

an understanding of stellar structure and its evolution will depend on an understanding of stellar streams. Two examples of this possible dependence are:

(1) The presence of stars born of heavy element enriched material that are now found to have ages from less than  $10^8$  yr to more than  $10^{10}$  yr (e.g., Eggen & Sandage 1969; Eggen 1995b) indicates that nearly complete enrichment of the disk took place at its formation. However, the Pleiades ( $\sim 10^8$  yr), Hyades ( $\sim 10^9$  yr), and HR 1614 ( $\sim 4 \times 10^9$  yr) superclusters, all with  $[\text{Fe}/\text{H}] = +0.1$  dex, are in separate streams with IC 2391, the Pleiades and the Hyades in the young disk on outbound orbits, and the HR 1614 supercluster in the old disk and nearly permanently at the solar circle.

(2) The young disk and old disk stars (e.g., Eggen 1989) are easily distinguishable by their motion. However, additional population groups, such as "old thick disk" or "old thin disk," have recently been added to the vocabulary of stellar structure and these are not distinguishable star by star but only by group characteristics. The possibility that these groupings arise from combining stars from several streams is discussed in Sec. 2. In the present discussion use is made of photometric luminosities, determined from calibrations of various photometric systems, such as

| Stars      | System                     | Reference           |
|------------|----------------------------|---------------------|
| A          | Strömgren, $H\beta$        | Eggen (1977)        |
| AF         | Strömgren, Geneva          | Eggen (1995a)       |
| GK (MS)    | Strömgren, Geneva          | Eggen (1986, 1995b) |
| GK (Giant) | Strömgren, DDO, Geneva, RI | Eggen (1993a, 1994) |
| M (Giant)  | RI                         | Eggen (1992b)       |

The Strömgren photometry is mainly from Hauck & Mermilliod (1980) and the Geneva photometry is from Rufener (1988). The DDO results are mainly from McClure & Forrester (1981) and the unpublished values of my own and the RI photometry is mainly my own.

## 2. STREAM II

The members of Stream II (Ursa Major) are identified by the convergent point  $(A, D) = (20^\circ 55', -38^\circ 1')$ , of the proper motion of members of the Sirius supercluster (Eggen 1992d). This supercluster contains the Ursa Major Cluster but the convergent point determinations of the proper motions in this sparse cluster are complicated by the circumstance that the cluster stars are strung out along a great circle that also passes through the convergent point (Brown 1950). The wider distribution of the supercluster members avoids this difficulty. Stars are accepted as stream members if  $\pi v < 0.1 / \sin \lambda$ , where  $v$  and  $\tau$  are, respectively, the components of the proper motion in the direction of, and perpendicular to the direction of  $(A, D)$  and  $\lambda$  is the angular separation of the star and  $(A, D)$ . The basic relations for moving clusters are

| HD    | $D$    | $X$    | $V_{\text{TOT}}$ | Sp.T.     |
|-------|--------|--------|------------------|-----------|
| 11428 | 295 pc | 197 pc | +17.7            | KI III    |
| 1227  | 132    | 25     | +18.6            | G8 II-III |

Because the  $V$  velocity of the supercluster is so small,  $U/V \sim 11$ , makes it possible to ignore the small deviations in

$$\pi = 4.74 v / V_{\text{TOT}} \sin \lambda, \quad (1)$$

$$\text{Peculiar velocity} = \text{P.V.} = 4.74 \tau D \text{ (pc)}, \quad (2)$$

where  $V_{\text{TOT}}$  is the total space velocity of the supercluster. If we set a limit, for stream membership, of the peculiar velocity at 10% of  $V_{\text{TOT}}$ ,  $\text{P.V.} = 0.1 V_{\text{TOT}}$ , then  $\pi v < 0.1 \sin \lambda$  follows from Eqs. (1) and (2). Also from Eq. (1)

$$V_{\text{TOT}} = 4.74 v D (\text{pc}) / \sin \lambda, \quad (3)$$

and the values of  $V_{\text{TOT}}$  can be derived from photometric luminosities. The stars of the Bright Star Catalogue (HR stars) that are also included in the four catalogues,

|                |                           |             |
|----------------|---------------------------|-------------|
| FK5            | Fricke <i>et al.</i> 1988 | (HR stars)  |
| FK5 Extension  | Fricke <i>et al.</i> 1991 | (HR stars)  |
| FK5 Supplement | Schwan <i>et al.</i> 1993 | (HR stars)  |
| Nearby Stars   | Gliese (1969)             | (all stars) |

have been examined for stream membership and the members that are *not* also members of the Sirius supercluster, are listed in Table 1. Only stars with  $\sin \lambda > 0.45$  and  $V_{\text{TOT}} > 10$  km/s have been included. In addition to the photometric luminosity and the computed total space motion, ratios of  $\tau$  and  $v$ , values of  $\sin \lambda$  and the observed and computed values of the radial velocity,  $\rho(\text{comp}) = V_{\text{TOT}} \cos \lambda$ , are also included. The supercluster members are in Table 2. The mean difference between the cluster luminosities and the photometric values is  $0.00 \pm 0.15$  mag, whereas  $\rho(\text{clus}) - \rho(\text{obs}) = -0.1 \pm 2.4$  km/s.

The three other well-established young disk superclusters, in addition to the Sirius supercluster, are

| SC       | Stream | $(A, D)$                   | $V_{\text{TOT}}$ |
|----------|--------|----------------------------|------------------|
| Hyades   | I      | $(6^\circ 4', 6^\circ 5')$ | $42.3 + 0.045X$  |
| Pleiades | O      | $(5.98, -35.15)$           | $26.5 + 0.025X$  |
| IC 2391  | ...    | $(5.82, -12.44)$           | $27.4 + 0.035X$  |

where  $X$  is the galactic, radial distance from the sun. All of these superclusters (a) have  $P[\text{Fe}/\text{H}] \sim 0.1$  dex and (b) take part in a general galactic expansion of some 45 km/s/kpc. The basic assumption concerning moving clusters and superclusters is that the orbits of individual members are isoperiodic, so the  $V$  velocity will depend on the radial distance from the Sun

$$dV/dX = -(A - B) = -0.026 \text{ (Woolley 1965)}.$$

The coefficient of  $X$  in the expressions listed above for  $V_{\text{TOT}}$  will depend on the ratio of  $U$  and  $V$  velocities.

All three superclusters listed above are on outbound ( $+U$ ) orbits but the Sirius supercluster differs in two respects (a) the orbits are inbound ( $-U$ ) and (b) the heavy element abundance is solar, as will be discussed below. Also, the supercluster members in Table 2 show no evidence of the galactic expansion term in the values of  $V_{\text{TOT}}$  derived from the photometric luminosities,

| HD     | $D$    | $X$   | $V_{\text{TOT}}$ | Sp.T. |
|--------|--------|-------|------------------|-------|
| 34109  | 158 pc | 86 pc | +20.8            | A0 V  |
| 141003 | 45     | -27   | +17.1            | A1 V  |

$V$ , caused by the isoperiodicity requirement, over the range of  $X$  discussed here.

TABLE 3. Space motions and positions of members in the Sirius supercluster.

| HD       | U     | V<br>km/sec | W     | X    | Y<br>PARSECS | Z    |
|----------|-------|-------------|-------|------|--------------|------|
| FK5      |       |             |       |      |              |      |
| 33111    | -14.5 | +2.7        | -11.6 | +24  | -11          | -12  |
| 38392/3  | -15.7 | +1.9        | -12.2 | +5   | -5           | -3   |
| 40183    | -15.0 | +1.2        | -10.9 | +33  | +7           | +6   |
| 48915    | -15.1 | +1.1        | -10.9 | +2   | -2           | 0    |
| 78045    | -14.0 | +1.2        | -12.4 | -8   | -38          | -9   |
| 78922    | -14.1 | +1.1        | -12.2 | +18  | -73          | +15  |
| 91480    | -15.0 | +1.0        | -10.9 | +13  | +7           | +18  |
| 95418    | -14.6 | +1.5        | -10.2 | +11  | +7           | +18  |
| 102070   | -16.2 | +2.0        | -8.3  | -13  | -63          | +58  |
| 103287   | -14.9 | +1.5        | -11.9 | +9   | +7           | +22  |
| 106591   | -15.0 | +1.2        | -11.1 | +8   | +9           | +21  |
| 112185   | -14.6 | +1.8        | -10.3 | +6   | +10          | +22  |
| 116656/7 | -14.9 | +1.5        | -11.2 | +5   | +11          | +21  |
| 134083   | -15.2 | 0.0         | -10.7 | -6   | +5           | +13  |
| 139006   | -14.8 | +2.5        | -9.0  | -11  | +10          | +21  |
| 141003   | -14.3 | +3.2        | -11.3 | -29  | +14          | +36  |
| 172864   | -15.2 | +1.0        | -10.6 | +41  | +87          | +51  |
| FK EXT   |       |             |       |      |              |      |
| 34109    | -14.6 | +1.1        | -11.6 | +77  | +101         | +61  |
| 109799   | -14.8 | +0.7        | -11.3 | -13  | -23          | +19  |
| 110066   | -14.8 | +2.4        | -11.2 | +16  | +14          | +128 |
| 150706   | -16.2 | +0.6        | -9.4  | +9   | +21          | +14  |
| 180777   | -14.3 | +1.0        | -11.4 | +7   | +23          | +11  |
| FK Sup   |       |             |       |      |              |      |
| 1227     | -15.2 | +1.8        | -10.5 | +25  | +74          | -107 |
| 11428    | -15.5 | +2.2        | -10.0 | +207 | +204         | -109 |
| 32977    | -15.0 | +0.6        | -11.0 | +49  | -2           | -11  |
| 75065    | -14.9 | +1.1        | -11.2 | +19  | -73          | +9   |
| 111397   | -15.0 | +1.0        | -11.0 | -11  | -21          | +102 |
| 140160   | -14.8 | +2.0        | -11.1 | -48  | +19          | +58  |
| Gliese   |       |             |       |      |              |      |
| 227      | -14.9 | +1.3        | -11.1 | +15  | -4           | -1   |
| 457      | -15.1 | +1.0        | -11.7 | +10  | +11          | +23  |
| 503.2    | -14.5 | +1.9        | -9.0  | +6   | +11          | +22  |
| 509.1    | -15.1 | +0.9        | -10.8 | +5   | +12          | +4   |
| 9417     | -14.8 | +1.4        | -9.7  | +8   | +11          | +21  |

The individual values of the  $U, V, W$  velocity vectors and the  $X, Y, Z$  distances are listed in Table 3.  $X(U)$  is directed away from the galactic center,  $Y(V)$  is directed toward galactic rotation and  $Z(W)$  is directed toward the North galactic Pole. The mean space motion vectors are

| $U$       | $V$       | $W$        |
|-----------|-----------|------------|
| -14.9     | +1.4      | -10.9 km/s |
| $\pm 0.5$ | $\pm 0.7$ | $\pm 1.0$  |

The  $(M_v, B-V)$  diagram for the supercluster members is shown in Fig. 1, where the FK5 stars in the UMa cluster are represented by clear circles and the non-cluster supercluster members by closed circles. The Gliese stars in the cluster are represented by crossed circles and the noncluster, supercluster members by crosses. The isochrones for  $t=4$  and  $6 \times 10^8$  yr are from VanDenBergh (1985) with  $[\text{Fe}/\text{H}] \approx 0.00$ . The distributions of the stars in the catalogues are as follows:

|          | Stream | Supercluster | %SC |
|----------|--------|--------------|-----|
| FK5      | 35     | 19           | 54  |
| FK5 EXT  | 13     | 4            | 30  |
| FK5 SUPP | 16     | 6            | 38  |
| Gliese   | 21     | 10           | 48, |

and 45% of the stream members belong to the supercluster. In Eggen 1996b the possibility that only about one half the stars within some 25 pc of the sun are known, was based on the absence from the Gliese catalogue of members of low velocity superclusters. This is not the case with the Sirius supercluster, a circumstance almost certainly caused by the fact that half the supercluster stars in the Gliese catalogue are members of the UMa cluster and were placed on parallax programs for that reason.

Stream II is shown in the  $U, V$  velocity space of Fig. 2 where the Stream I (Hyades and NGC 1901), Stream 0 (Pleiades), and IC 2391 Stream stars are also represented. The

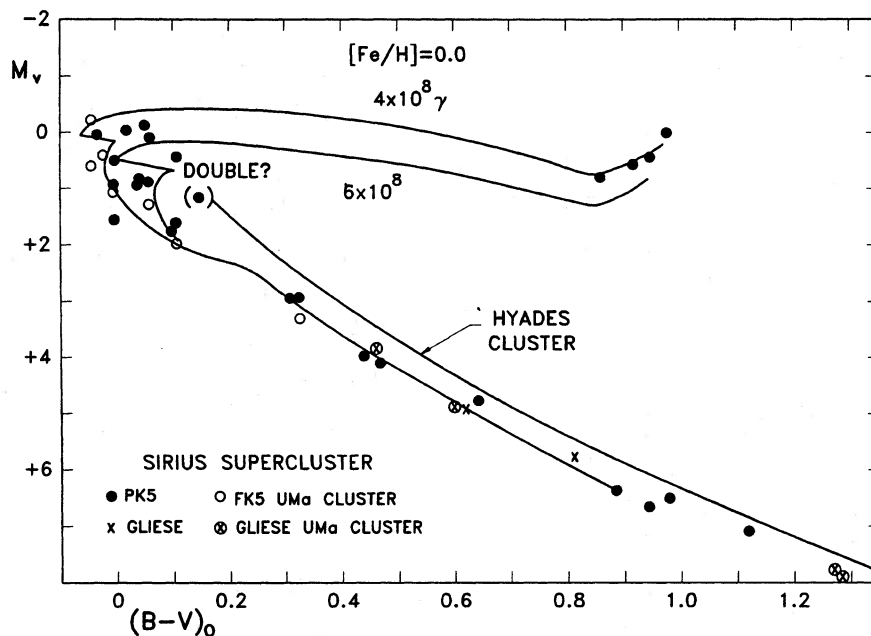


FIG. 1. Color-luminosity array for the Sirius supercluster.

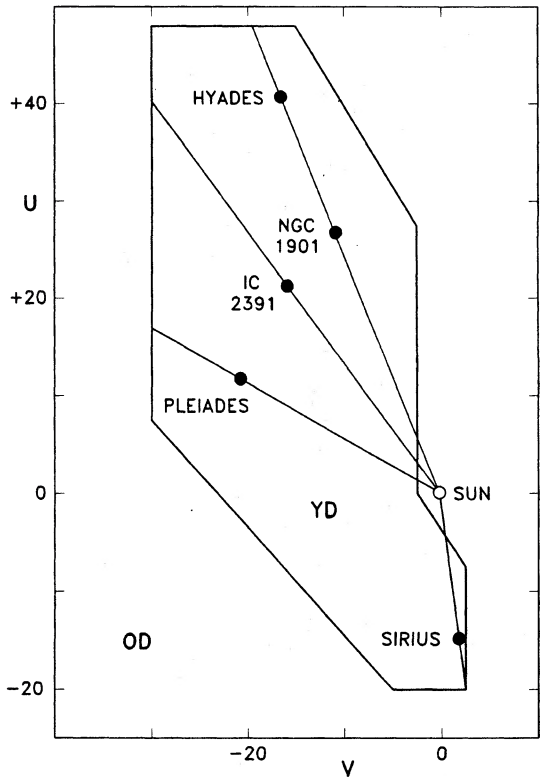


FIG. 2. Young disk streams in  $(U, V)$  velocity space.

enclosed region is the domain of the young disk (YD,  $t < 2 \times 10^9$  yr) stars.

The distribution of values of  $V_{TOT} = 25\text{--}35$  km/s in Fig. 3 contains 15 stars, or 18% of the stream members. With  $V_{TOT}$  near 30 km/s these stream members would be outside the domain of young disk stars and so if this excess is meaningful, it probably represents a stellar group rather than a supercluster. This possibility will be investigated elsewhere with a larger stellar sample. The distribution of  $V_{TOT}$  values for

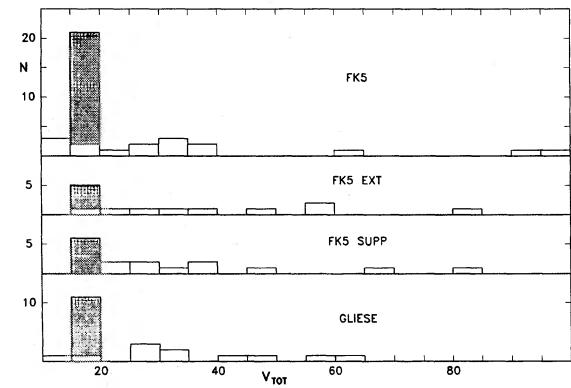


FIG. 3. Distribution of total space motions determined from photometric luminosities of Stream II stars.

stream members is shown in Fig. 3 where the hatched regions represent supercluster members.

Additional photometry of Sirius supercluster members is listed in Table 4. The values of the Geneva system parameters B2–V1 and the metallicity index  $m_2$  are compared with Hyades cluster stars in Fig. 4 and the gravity corrected CN index,  $C_m$  (McClure 1970) is compared with Hyades cluster dwarfs in Fig. 5. The small displacement in  $m_2$  from the Hyades stars indicates  $P[\text{Fe}/\text{H}] \sim 0.00$  (Eggen 1992d). The space distribution of the supercluster members is shown in Fig. 6 where closed circles represent non-cluster supercluster members and open circles, members of the UMa cluster.

3. THE SOLAR CIRCLE STREAM

The stars that make up the HR 1614 aggregate present several unique features (Eggen 1992a): (a) those near the sun still form a supercluster whereas others are only recognized as group members, (b) the former constitute the only supercluster thus far found amongst old disk population stars, and

TABLE 4. Additional photometry in the Sirius supercluster.

| HD       | (B2-V1) <sub>o</sub> | d                  | $m_2$               | (45-48) <sub>o</sub> | (42-45) <sub>o</sub> | (Cm) <sub>o</sub>  | I <sub>o</sub> | (R-I) <sub>o</sub> | E(b-y)             |
|----------|----------------------|--------------------|---------------------|----------------------|----------------------|--------------------|----------------|--------------------|--------------------|
| 1227     | 0 <sup>m</sup> 611   | 0 <sup>m</sup> 499 | -0 <sup>m</sup> 202 | 1 <sup>m</sup> 157   | 0 <sup>m</sup> 795   | 0 <sup>m</sup> 174 | 5.42           | 0 <sup>m</sup> 315 | 0 <sup>m</sup> 000 |
| 11428    | 0.936                | 0.438              | 0.028               | 1.320                | 1.066                | 0.260              |                |                    | 0.037              |
| 24160    | 0.619                | 0.500              | -0.189              | 1.165                | 0.791                | 0.171              | 3.48           | 0.317              | 0.000              |
| 38392    | 0.593                | 0.378              | -0.115              | 1.110                | 0.977                | 0.192              | 5.37           | 0.340              | 0.000              |
| 38393    | 0.260                | 0.741              | -0.472              | 0.958                | 0.512                | 0.308              | 3.33           | 0.160              | 0.000              |
| 41593    | 0.502                | 0.475              | -0.259              | 1.076                | 0.822                | 0.143              |                |                    | 0.000              |
| 75605    | 0.574                | 0.544              | -0.247              | 1.126                | 0.758                | 0.147              | 4.50           | 0.303              | 0.009              |
| 91480    | 0.137                | 0.971              | -0.496              |                      |                      |                    |                |                    | 0.000              |
| +59.1428 | 0.855                | 0.159              | 0.092               |                      |                      |                    | 8.64           | 0.555              | 0.000              |
| 102070   | 0.647                | 0.498              | -0.175              | 1.169                | 0.803                | 0.214              | 3.94           | 0.325              | 0.000              |
| 109799   | 0.129                | 1.044              | -0.502              |                      |                      |                    |                |                    | 0.000              |
| +58.1441 | 0.846                | 0.203              | 0.061               |                      |                      |                    | 8.29           | 0.570              | 0.000              |
| 115043   | 0.356                | 0.593              | -0.410              |                      |                      |                    | 8.29           | 0.570              | 0.000              |
| 134083   | 0.209                | 0.826              | -0.486              |                      |                      |                    |                |                    | 0.000              |
| 150706   | 0.355                | 0.597              | -0.409              | 1.023                | 0.662                | 0.106              |                |                    | 0.000              |
| 180777   | 0.105                | 1.063              | -0.503              |                      |                      |                    |                |                    | 0.000              |

(c) the members have a Hyades abundance of heavy elements ( $[\text{Fe}/\text{H}] \sim 0.1$  dex) but the CN strengths are the greatest observed. It is probable that circumstance (b) is a consequence of (c), which attracts special attention. The HR 1614 stars form part of a stream, here labeled the "Solar Circle Stream," the constituents of which are characterized by the three stars that give their names to the included stellar groups:

| Star           | $\mu\alpha/\mu\delta$<br>0°000 | $l/\tau$<br>0°000 | P.V.<br>(km/s) | $\pi$<br>TRIG | $V_{\text{TOT}}$<br>(km/s) | $U$ | $V$<br>(km/s) | $W$ | $R_{\text{max}}$<br>(kpc) | $R_{\text{min}}$ | $e$  |
|----------------|--------------------------------|-------------------|----------------|---------------|----------------------------|-----|---------------|-----|---------------------------|------------------|------|
| HR 1614        | 549/-1106                      | 1234/-29          | -1.3           | 0°110         | 61                         | -15 | -58           | -11 | 10.6                      | 6.2              | 0.26 |
| Arcturus       | -1099/-1995                    | 2275/115          | +5.6           | 0.097         | 114                        | -20 | -112          | -3  | 10.2                      | 3.8              | 0.45 |
| Kapteyn's star | 6570/-5726                     | 8710/278          | +5.1           | 0.356         | 285                        | -19 | -280          | -50 | 10.1                      | 0.               | 0.91 |

The values of  $V_{\text{TOT}}$  are determined from  $\pi$  (Trig) and Eq. (3) and the convergent point of the proper motions of the HR 1614 supercluster is adopted. The values  $R_{\text{max}}$ ,  $R_{\text{min}}$ , and  $e = R_{\text{max}} - R_{\text{min}} / R_{\text{max}} + R_{\text{min}}$  are from the Lynden-Bell potential (Eggen *et al.* 1962) with an assumed value of  $R(\text{sun}) = 10$  kpc. Obviously the stream stars spend most of their lifetimes near the solar circle.

### 3.1 HR 1614 Supercluster and Group

The HR 1614 supercluster and group contain members with (a) the overabundance of the Hyades, (b) an age near  $4 \times 10^9$  yr, and (c) the strongest CN observed in the solar neighborhood. The convergent point of the proper motions of supercluster stars in Table 5 is  $(A, D) = (8^h 72, -58^s 8)$ . This differs very little from the previous determination (Eggen 1992a) of  $(A, D) = (8^h 38, -58^s 3)$ . The total space velocity is  $V_{\text{TOT}} = 60.7 + 0.026X$  km/s, where  $X$  is the radial distance from the Sun. The dependence on  $X$  reflects the variation in the  $V$  velocity necessary to maintain isoperiodicity of the members:  $dV/dX = -(A - B)$ , where  $A$  and  $B$  are the Oort constants of galactic rotation (Kerr & Lynden-Bell 1986). The proper motions are on the FK5 system and are mainly from the FK5 and its extension and supplement and from the Carlsberg (e.g., 1988) meridian catalogues. The group members are listed in Table 6 where the adopted value of  $V = -59.5 - 0.026X$  km/s leads to the group parallax.

The group and supercluster stars are shown in the  $(M_V, B - V)$  plane of Fig. 7 where the main sequence of the Hyades cluster (Schwan 1991) is labeled. The  $4 \times 10^9$  yr isochrone is from Castellani *et al.* (1992) for  $(Y, Z) = (0.27, 0.02)$ . The published values of  $B - V$  are corrected

by +0.07 mag (Eggen 1995a). The two blue stragglers are

| HD     | $M_V$ | $B - V$ | $SpT$             |
|--------|-------|---------|-------------------|
| 203875 | +1.49 | 0.21    | A9 V supercluster |
| 108846 | +3.13 | 0.47    | dF8 group         |

Table 7 contains additional (Geneva, DDO, RI) photometry of HR 1614 group and supercluster members. The metallicity indices from the Geneva photometry,  $m_2$ , for the main sequence stars are compared with the Hyades values (Eggen 1986) in Fig. 8. The Hyades and HR 1614 appear to have the same heavy element abundance except, perhaps, for 3 or 4 stars with  $B2 - V1 = 0.68 - 0.75$  mag (K5 V). However, this color marks the onset of TiO bands and these could be a disturbing feature. The HR 1614 giants have experienced a different evolutionary history than those in the Hyades so it is perhaps more appropriate to compare them with M67 giants, whose history is similar, and this is done in Fig. 9. The metallicity of M67 is near solar so that of the HR 1614 giants appears to match well the results for the dwarfs in Fig. 8.

The continuous curve in Fig. 10 represents the mean values of the gravity corrected CN index,  $(C_m)_0$ , for field stars (McClure 1970). The Hyades giants lie near this relation. The CN strengths of the HR 1614 stars are represented by closed (supercluster) and open (group) circles. The two labeled stars show abnormally strong CN which, in one case (V645 Mon = HD 65953) represents an irregular light variable. The HR 1614 stars in Fig. 10 represent the strongest CN stars found near the sun and about one-half the known stars with this strength are group members. The dwarfs in Fig. 11 show a similar result. The crosses in the later figure represent individual Hyades cluster members (Goodenough 1966).

The position of the HR 1614 stars in the  $(X, Y)$  and  $(Z, Y)$  planes is shown in Figs. 12 and 13, respectively. The dispersion of stars in these figures may contain information concerning cluster disruption, which will be available when larger samples of group members are obtained. The  $(X, Y, Z)$

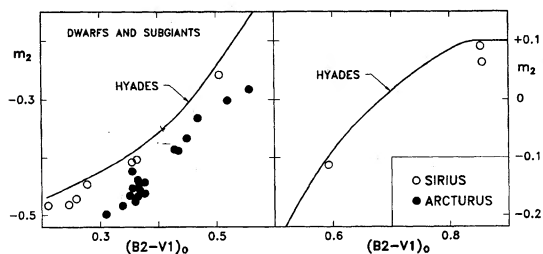


FIG. 4. Metallicity of Sirius supercluster and Arcturus group, near main sequence members.

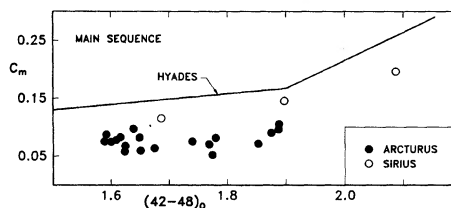


FIG. 5. CN strength of Arcturus group and Sirius supercluster main sequence stars.

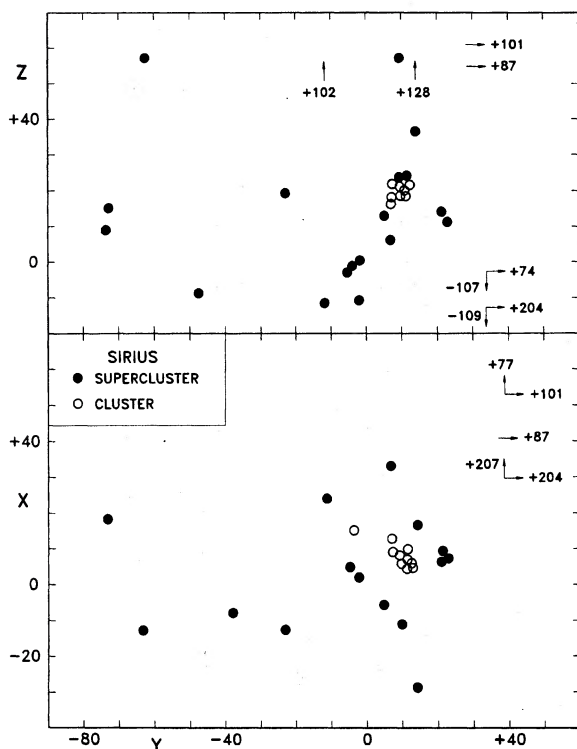


FIG. 6. Spatial distribution of the Sirius supercluster members.

coordinates for the supercluster members are in Table 8 which also contains the space motion vectors. The mean space motions are

|              | $U$  | $V$   | $W$   | $\sigma(U)$ | $\sigma(V)$ | $\sigma(W)$ |
|--------------|------|-------|-------|-------------|-------------|-------------|
| HR 1614      | -5.8 | -59.6 | -11.4 | $\pm 2.0$   | $\pm 2.0$   | $\pm 2.0$   |
| Supercluster |      |       |       |             |             |             |
| Group        | +5   | -59.5 | -6    | $\pm 17$    | $\pm 1.5$   | $\pm 14$    |

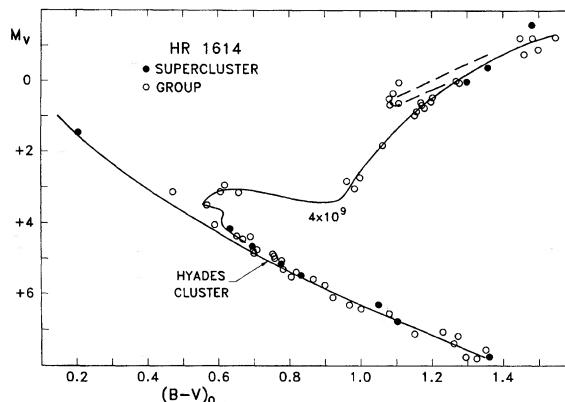


FIG. 7. Color-luminosity array for the HR 1614 supercluster and group.

The dispersion in  $V$  for the group stars (Table 6) is entirely the result of the spread in the values of  $X$ . The distribution of the group members in  $(U, W)$  velocity space is shown in Fig. 14. The circle that includes these values has a radius of 35 km/s and represents the tube that contains the dispersed orbits. The  $V$  velocity,  $(-59.5 - 0.026X)$  km/s, represents the period required to bring the star to its present position. The disrupted group members with  $V$  velocities more than  $\pm 0.5$  km/s from this value will not appear in our limited observation horizon (Woolley 1965).

### 3.2 Arcturus Group

The Arcturus group has an age near  $10^{10}$  yr and an abundance of heavy elements near  $[\text{Fe}/\text{H}] = -0.5$  dex (e.g., Eggen 1987). The best documented group members are listed in Table 9 where the adopted modulus is from  $V = (-110 - 0.026X)$  km/s. The stars are represented with clear circles in Fig. 15 where the isochrones for  $7 \times 10^9$  and  $13 \times 10^9$  yr are

TABLE 5. Members of the HR 1614 supercluster.

| HD      | $\mu_\alpha/\mu_\delta$<br>0''001 | $v/r$<br>0''001 | $\Delta T$<br>km/sec | $\sin i$ | $X$<br>pc | $V_{TOT}$<br>km/sec | $MOD$<br>km/sec | $V_0$  | $(B-V)_0$ | Clus                | $M_V$<br>Photo      | $\rho$<br>Obs | Clus  | Sp.T.   | Name      | Note |
|---------|-----------------------------------|-----------------|----------------------|----------|-----------|---------------------|-----------------|--------|-----------|---------------------|---------------------|---------------|-------|---------|-----------|------|
| 12051   | 246/-249                          | 427/-17         | -2.0                 | 0.834    | +16.9     | 61.5                | 2.00            | 7.15   | 0.78      | +5 <sup>m</sup> .15 | +5 <sup>m</sup> .30 | -35.2         | -33.8 | dG7     | +32.360   |      |
| 17215   | 152/-68                           | 166/10          | +2.1                 | 0.585    | -11.9     | 60.4                | 3.25            | (8.05) | 0.70      | +4.80               | --                  | +50.8         | +49.0 | G6 V    | -71.156   | X    |
| +2.816  | 150/-297                          | 333/1           | +0.1                 | 0.972    | +33.4     | 61.55               | 2.90            | 8.41   | 0.83      | +5.51               | +5.50               | +14.3         | +14.5 |         | G84-23    |      |
| 32147   | 549/-1106                         | 1234/-29        | -1.3                 | 0.929    | +7.8      | 60.9                | -0.07           | 6.22   | 1.05      | +6.29               | +6.50               | +22.3         | +22.6 | K3 V    | HR 1614   | X    |
| +5.1168 | 573/-3715                         | 3756/-150       | -2.2                 | 0.915    | +2.6      | 60.7                | -2.53           | 9.86   | 1.56      | +12.37              | +12.14              | +20.0         | +24.5 | M5      | G89-19    | X    |
| 96511   | -91/-177                          | 199/7           | +1.4                 | 0.615    | +19.9     | 61.2                | 3.00            | 7.15   | 0.635     | +4.15               | +4.20               | -46.8         | -48.2 | dG3     | +82.235   | X    |
| 114092  | -42/-64                           | 76/-6           | -4.5                 | 0.978    | +25.0     | 60.5                | 6.06            | 6.15   | 1.30      | +0.05               | +0.20               | -12.3         | -12.9 | K4 III  | HR 4956   |      |
| 115467  | -35/-65                           | 73/6            | +4.7                 | 0.911    | +71.5     | 58.95               | 5.96            | 6.70   | 1.10      | +0.74               | +1.00               | +24.2         | +24.3 | K0 III  | -14.3683  |      |
| 120323  | -40/-60                           | 72/6            | +3.9                 | 0.809    | -89.4     | 58.4                | 5.71            | 4.19   | 1.45      | -1.6                | -1.85               | +40.0         | +34.3 | M5 III  | HR 5192   | X    |
| 157881  | -574/-1183                        | 1317/-21        | -0.7                 | 0.730    | -7.7      | 60.5                | -0.22           | 7.54   | 1.36      | +7.76               | +8.11               | -23.0         | -22.2 | K7 V    | G19-24    | X    |
| 181480  | -11/-36                           | 37/-4           | -6.4                 | 0.998    | -250.2    | 53.4                | 7.39            | 7.02   | 1.36      | -0.37               | -0.37               | -3.7          | -2.9  | K5 III  | -26.14096 |      |
| 194640  | -12/-521                          | 521/11          | +1.2                 | 1.000    | -20.0     | 60.2                | 1.93            | 6.60   | 0.70      | +4.67               | +4.70               | -1.0          | -0.1  | G5 V    | -31.17597 | X    |
| 203875  | 16/-169                           | 170/-1          | -0.2                 | 0.935    | -39.8     | 59.65               | 4.20            | 5.69   | 0.21      | +1.49               | +1.46               | -20.6         | -21.1 | A9 V    | HR 8195   | X    |
| 210277  | 86/-451                           | 459/-4          | -0.5                 | 0.931    | -10.8     | 60.4                | 2.06            | 6.61   | 0.71      | +4.55               | --                  | -22.0         | -22.0 | G9 IV/V | -8.5818   | X    |
| 213042  | 227/-816                          | 846/36          | +2.6                 | 1.000    | -7.4      | 60.5                | 0.89            | 7.68   | 1.10      | +6.79               | +7.00               | +5.3          | +1.7  | K5 V    | -30.19175 | X    |

Notes to TABLE 5.

HD 17215AB  
HD 32147  
+5.1668  
+82.235  
HD 120323  
HD 157881  
HD 194640  
HD 203875  
HD 210277  
HS 213042

Separation near 0.5 arcsec,  $\Delta V \sim 1.0$  mag. Corrected for companion in the table.  
HR 1614. The cluster parallax is 0.104 arcsec and the mean trig. value is 0.110 arcsec.  
The cluster parallax is 0.316 arcsec and the trig. values range from 0.260 to 0.311 arcsec.  
Sp.B.,  $P = 18.9$ d.  
V806 Cen.  
Trig. parallax is 0.133 arcsec and the cluster value is 0.111 arcsec.  
Trig. parallax is 0.041 arcsec and the cluster value is 0.040 arcsec.  
Blue straggler.  
Trig. parallax is 0.048 arcsec and the cluster value is 0.039 arcsec.  
Trig. parallax is 0.070 arcsec and the cluster value is 0.066 arcsec.

TABLE 6. Members of the HR 1614 group.

| HD         | $\mu_{\alpha}/\mu_{\delta}$<br>0.001 | $\rho$<br>km/sec | MOD               | X<br>pc | U   | V<br>km/sec | W   | $V_0$             | (B-V) <sub>0</sub> | $M_V$<br>Clus      | $M_V$<br>Photo     | Sp.T.  | Y<br>pc | Z<br>pc | Name     | Note |
|------------|--------------------------------------|------------------|-------------------|---------|-----|-------------|-----|-------------------|--------------------|--------------------|--------------------|--------|---------|---------|----------|------|
| 55         | -140/-560                            | +41.6            | 1 <sup>m</sup> 86 | -10     | -36 | -59         | +11 | 8 <sup>m</sup> 46 | 1 <sup>m</sup> 08  | +0 <sup>m</sup> 60 | +6 <sup>m</sup> 85 | K5 V   | -12     | -18     | -68.3597 | X    |
| 2140       | 40/-45                               | -17.7            | 6.62              | 46      | +9  | -60.5       | -14 | 6.71              | 1.28               | +0.09              | +0.12              | K5 III | 113     | -172    | +6.43    | X    |
| 9312       | 128/-200                             | -4.5             | 3.90              | 31      | +6  | -60.5       | -30 | 6.75              | 0.96               | +2.85              |                    | K5     | 29      | -42     | +16.161  |      |
| 12235      | 232/-254                             | -18.0            | 0.73              | 18      | 0   | -60         | +4  | 5.86              | 0.61               | +3.13              | +3.39              | G1 IV  | 9       | -29     | HR 582   |      |
| 13403      | 268/-217                             | -33.8            | 2.59              | 23      | +12 | -60         | -17 | 6.98              | 0.65               | +4.39              |                    | G5 V   | 24      | -2      | +56.449  |      |
| 13825      | 460/-196                             | -1.6             | 2.40              | 20      | +38 | -60         | 0   | 6.81              | 0.64               | +4.41              |                    | G8 IV  | 14      | -17     | +23.303  |      |
| 13997      | 229/-223                             | -23.6            | 3.00              | 25      | +1  | -60         | +3  | 7.99              | 0.76               | +4.99              |                    | G5     | 13      | -28     | G 4-9    |      |
| 15590      | 102/-52                              | +36.8            | 4.85              | 9       | +16 | -59.5       | -12 | 8.00              | 0.66               | +3.15              | +3.3:              | G3 V   | -38     | -85     | -42.834  | X    |
| 17660      | 346/-398                             | -25.0            | 1.73              | 16      | -9  | -60         | +4  | 8.90              | 1.27               | +7.17              | +7.08              | GK 6   | 6       | -14     | G 4-43   |      |
| 19305      | 391/-928                             | -31.3            | 0.55              | 9       | -34 | -59.5       | +7  | 9.00              | 1.35               | +8.50              | +8.35              | M0 V   | 1       | -9      | G 76-58  |      |
| 22403      | 239/-271                             | -19.4            | 2.49              | 28      | -4  | -60         | 0   | 7.34              | 0.70               | +4.85              | +4.50              | G2 V   | 8       | -12     | G 6-20   |      |
| 28479      | 42/-109                              | +26.0            | 5.18              | 67      | -19 | -61         | -15 | 5.78              | 1.17               | +0.60              | +0.82              | K1 III | -50     | -70     | HR 1421  | X    |
| +18.683    | 651/-1125                            | +26.0            | -0.03             | 9       | +22 | -60         | -16 | 9.96              | 1.52               | +9.99              | +10.25             | M2 III | 0       | -3      | G 8-55   |      |
| 33042      | 71/-3                                | +36.0            | 6.08              | 31      | +13 | -60         | +22 | 4.9V              | 1.48               | -1.2V              | -1.2               | M3     | -12.7   | -100    | HR 1663  |      |
| 36395      | 771/-2113                            | +7.7             | -1.07             | 5       | -25 | -59.5       | -11 | 7.97              | 1.47               | +9.04              |                    | M1 V   | -3      | -2      | G 99-15  | X    |
| +62.780    | 291/-788                             | -19.3            | 0.90              | 13      | +15 | -60         | -13 | 9.02              | 1.40               | +8.22              | +8.37              | M0 V   | 7       | 4       | G 249-18 |      |
| 38358      | 9/-88                                | -23.7            | 6.00              | 154     | -7  | -63.5       | -31 | 6.05              | 1.27               | +0.05              |                    | GK0    | 32      | 19      | HR 1979  |      |
| 40020      | 106/-58                              | +21.0            | 5.15              | 102     | +8  | -62         | +32 | 5.84              | 1.085              | +0.69              | +0.62              | K2 III | -30     | -12     | HR 2026  |      |
| 40176      | 36/-26                               | +59.5            | 4.95              | 40      | +12 | -60.5       | -14 | 4.97              | 1.11               | +0.15              | +0.15:             | K1 III | -78     | -44     | HR 2087  | X    |
| 43429      | 37/-63                               | +63.6            | 4.15              | 45      | +21 | -60.5       | -14 | 5.98              | 1.06               | +1.83              | +1.50              | K1 III | -46     | -19     | HR 2243  |      |
| 45067      | 340/-222                             | +45.0            | 2.31              | 25      | +18 | -60         | +10 | 5.87              | 0.57               | +3.56              | +3.50              | F8 V   | -15     | -3      | HR 2313  |      |
| 57901      | 83/-435                              | +38.5            | 1.87              | 21      | +16 | -60         | -4  | 8.20              | 0.965              | +6.33              | +6.25              | K4 V   | -10     | 5       | G 89-16  |      |
| 65953      | 68/-73                               | +26.7            | 5.30              | 82      | -10 | -61.5       | +23 | 4.55              | 1.465              | -0.75              |                    | K4 III | -75     | 28      | HR 3141  | X    |
| +10.1857AB | 224/-616                             | +20.4            | 1.42              | 13      | -19 | -60         | +4  | 9.65              | 1.39               | +8.23              | +8.00              | M0     | -10     | 9       | G 96-1   | X    |
| +81.297    | -10/-450                             | -21.4            | 2.24              | 16      | +14 | -60         | +15 | 11.80             | 1.54               | +10.08             | +10.14             | M5     | 18      | 15      | G 46-2   | X    |
| 84035      | 36/-827                              | -12.1            | 0.93              | 10      | -13 | -59.5       | -3  | 9.30              | 1.23               | +7.06              | +7.30              | K5 V   | 0       | 12      | G 253-26 |      |
| 90711      | -371/-281                            | +30.4            | 2.26              | 7       | +30 | -59.5       | -24 | 8.12              | 1.15               | +7.19              | +6.95              | K3 V   | -20     | 19      | G 116-42 |      |
| 97457      | 19/-119                              | +17.8            | 5.32              | 30      | -32 | -60.5       | +6  | 7.86              | 0.805              | +5.60              | +5.75              | K0 V   | -38     | 104     | G 55-22  | X    |
| 103246     | -51/-125                             | -35.8            | 4.14              | 31      | -7  | -60.5       | +4  | (10.39)           | 0.78               | +5.07              |                    | K0 V   | 39      | 46      | +17.2328 | X    |
| 106869     | -282/-46                             | +41.3            | 2.77              | -16     | +20 | -59         | -4  | 6.81              | 0.59               | +4.04              | +4.0:              | F8 V   | 39      | 46      | +74.476  | X    |
| 107325     | -65/-101                             | -13.9            | 5.15              | 11      | +2  | -59.5       | -18 | 5.49              | 1.09               | +0.34              | +0.60              | G1 V   | -31     | 8       | -48.7307 |      |
| 108846     | -117/-115                            | +0.6             | 4.53              | 14      | +17 | -60         | +6  | 7.66              | 0.47               | +3.13              | +3.40              | GK2    | -8      | 106     | HR 4693  |      |
| +9.2636    | -635/-518                            | +17.7            | 0.92              | -1      | +19 | -59.5       | +1  | 9.73              | 1.45               | +8.87              | +8.88              | M1     | -5      | 14      | +40.2572 |      |
| 112164     | -219/-219                            | +32.0            | 3.01              | -21     | +10 | -59         | -28 | 5.89              | 0.62               | +2.88              | +3.00              | G2 IV  | -31     | 13      | G 12-34  |      |
| 117267     | -42/-61                              | +39.4            | 5.82              | -56     | -12 | -58         | +19 | 6.33              | 1.085              | +0.51              | +0.57              | K0 III | -46     | 127     | HR 4903  |      |
| 118742AB   | -282/-143                            | -24.0            | 3.00              | -1      | +22 | -59.5       | -8  | 7.76              | 0.71               | +4.76              |                    | G5 V   | 11      | 38      | HR 5078  | X    |
| 119217     | -159/-425                            | +44.9            | 1.91              | -10     | -29 | -59         | +20 | 9.15              | 0.92               | +6.15              |                    | GK5    | -6      | 21      | G 165-22 | X    |
| -44.8976   | -144/-41                             | +41.4            | 3.92              | -41     | +2  | -58.5       | +10 | 9.76              | 1.29               | +7.85              | +7.90              | M0 V   | -41     | 17      | G 62-62  |      |
| 122443     | -49/-84                              | -33.7            | 5.60              | -42     | +1  | -58.5       | -33 | 6.27              | 1.195              | +0.67              | +5.73              | K2 V   | 5       | 125     | +18.2813 |      |
| +30.2512   | -633/-302                            | -38.3            | 1.14              | -4      | +27 | -59.5       | -20 | 8.56              | 1.26               | +7.42              | +7.49              | G5     | 4       | 16      | G 166-22 |      |

TABLE 6. (continued)

| HD     | $\mu_\alpha/\mu_\delta$<br>0".001 | $\rho$<br>km/sec | MOD  | X<br>pc | U   | V<br>km/sec | W   | $V_0$ | (B-V) <sub>0</sub> | $M_V$<br>Clus | Sp.T.    | Y<br>pc  | Z<br>pc  | Name      | Note |
|--------|-----------------------------------|------------------|------|---------|-----|-------------|-----|-------|--------------------|---------------|----------|----------|----------|-----------|------|
| 126583 | -294/-127                         | +0.9             | 3.18 | -19     | +24 | -59         | +16 | 8.05  | 0.75               | +4.87         | G9 V     | 2        | 39       | G 85-51   | X    |
| 132345 | -105/-62                          | -13.0            | 5.22 | -82     | +30 | -57.5       | -2  | 5.69  | 1.205              | +0.47         | K3p III  | -20      | 72       | HR 5582   | X    |
| 136834 | -363/-367                         | -29.2            | 1.86 | -16     | +20 | -59         | -17 | 8.32  | 1.00               | +6.46         | K3 V     | 1        | 17       | G 15-20   |      |
| 139997 | -38/-103                          | -5.0             | 5.41 | -105    | +2  | -57         | -28 | 4.58  | 1.50               | -0.83         | K5 III   | -21      | 56       | HR 5838   |      |
| 141477 | -51/-88                           | -38.7            | 5.05 | -58     | +3  | -58         | -24 | 3.84  | 1.55               | -1.21         | M0.5 III | 34       | 77       | HR 5874   |      |
| 146388 | -71/-89                           | -17.8            | 5.02 | -61     | -11 | -58         | +2  | 5.69  | 1.11               | +0.67         | K3 III   | 41       | 64       | HR 6065   |      |
| 158633 | -526/10                           | -38.4            | 1.50 | +2      | 0   | -59.5       | +20 | 6.44  | 0.76               | +4.94         | K0 V     | 17       | 11       | HR 6518   |      |
| 159809 | -56/-156                          | +6.8             | 4.40 | -72     | +10 | -57.5       | -15 | 7.46  | 0.99               | +3.06         | K1 IV    | -19      | -10      | -45.8744  |      |
| 164326 | -28/-139                          | +3.8             | 4.82 | -87     | +16 | -57.5       | -17 | 9.28  | 0.67               | +4.46         | G4 IV    | -24      | -20      | -48.9629  |      |
| 166796 | -69/-141                          | -24.1            | 5.22 | -104    | +15 | -57         | 0   | 7.95  | 1.00               | +2.73         | K0 IV    | -25      | -26      | -47.8766  |      |
| 167876 | 3/112                             | -10.4            | 5.66 | -134    | +9  | -56         | -31 | 6.46  | 1.185              | +0.80         | K3 III   | 10       | -12      | -27.12658 |      |
| 178445 | -87/-641                          | +2.0             | 1.69 | -18     | +12 | -59         | -9  | 9.37  | 1.32               | +7.88         | K7 V     | -3       | -8       | -47.9196  |      |
| 182955 | -14/-46                           | -35.0            | 6.71 | -127    | -19 | -56         | -11 | 5.51  | 1.45               | -1.20         | M0 III   | 179      | 6        | HR 7391   |      |
| 191584 | -20/-101                          | -0.8             | 5.34 | -99     | +2  | -57         | +2  | 6.06  | 1.175              | +0.72         | K1 III   | -4       | -63      | HR 7706   |      |
| 206094 | 67/-179                           | +35.3            | 4.10 | -44     | -10 | -58.5       | -36 | 9.71  | 0.87               | +5.73         | K2 V     | -2       | -49      | -43.9497  |      |
| 215704 | 242/-6                            | -51.8            | 2.48 | 7       | +18 | -59.5       | 0   | 7.87  | 0.78               | +5.39         | K0       | 30       | -4       | +49.3937  |      |
| 219263 | 112/-112                          | +1.              | 4.68 | -35     | +26 | -58.5       | -9  | 5.68  | 1.155              | +1.00         | K2 III   | -5       | -79      | HR 8835   |      |
| 222013 | 97/-199                           | -2.6             | 3.80 | -21     | +7  | -59         | +10 | 9.21  | 0.82               | +5.41         | K0 V     | -9       | -53      | -46.10563 |      |
| 222804 | 59/-66                            | +24.7            | 5.72 | -48     | +9  | -58         | -20 | 6.64  | 1.165              | +0.92         | K1 III   | -23      | -129     | -46.10579 |      |
|        |                                   |                  |      |         | +5  | -59.5       | -6  |       |                    |               |          | $ W+20 $ | $\sigma$ |           |      |
|        |                                   |                  |      |         | +17 | +1.5        | +14 |       |                    |               |          |          |          |           |      |

Notes to TABLE 6.

Occultation binary but not confirmed.

Sp.B.,  $P = 36.6d$ .

Possibly composite. Also classified G5 IV.

Sp.B.,  $P = 1.9d$ . V 837 Tau,  $\Delta V = 0.09$  mag.

The luminosity indicates that this is almost certainly an undetected binary with near equal components. The trigonometric and cluster parallaxes are both 0.165 arcsec.

Possible BaII star (Eggen 1993b, Table 17 and Figure 7).

V 645 Mon,  $\Delta V \sim 0.02$  mag.

AB differ by 4 magnitudes and are separated by 2 arcsec. A is Sp.B.,  $P = 20.9d$ . C is 114 arcsec distant.

Sp.B.

Equal components separated by 0.02 arcsec.

ADS 8337AB.  $P = 76.8$  y and  $a = 0.398$  arcsec.  $\Delta m \sim 1.2$  mag.

ADS 8981AB, with components separated by 3 arcsec and 2.4 mag difference. C is 57 arcsec distant. The effect of the B component has been ignored.

Possibly variable velocity (Griffin 1971, Fouts 1987).

$\lambda$  4150 star with strong CN. Possibly variable velocity. A companion (G8 V) is 20 arcsec distant and may share the motion but the adopted modulus places it 0.75 mag above the main sequence,  $V = 10.11$ ,  $B-V = 0.85$ ,  $U-B = 0.50$  from 4 observations with the Hooker telescope. If B shares the motion of A it is probably an undetected close binary of equal components.

TABLE 7. Additional photometry of HR 1614 stars.

| HD<br>(Name)               | (B2-V1) <sub>0</sub> | m <sub>2</sub>       | (45-48) <sub>0</sub> | (42-45) <sub>0</sub> | (C <sub>m</sub> ) <sub>0</sub> | I <sub>0</sub>     | (R-I) <sub>0</sub>  | E(b-y)              |
|----------------------------|----------------------|----------------------|----------------------|----------------------|--------------------------------|--------------------|---------------------|---------------------|
| <b>Table 5</b>             |                      |                      |                      |                      |                                |                    |                     |                     |
| 12051                      | 0 <sup>m</sup> .489  | -0 <sup>m</sup> .282 |                      |                      |                                |                    |                     | 0 <sup>m</sup> .000 |
| 17215                      | 0.423                | -0.332               | 1 <sup>m</sup> .036  | 0 <sup>m</sup> .712  | 0 <sup>m</sup> .170            | 7 <sup>m</sup> .31 | 0 <sup>m</sup> .225 | 0.000               |
| +2.816                     |                      |                      | 1.090                | 0.856                | 0.198                          | 7.86               | 0.260               | 0.000               |
| 32417                      | 0.661                | -0.011               | 1.122                | 1.129                | 0.366                          | 5.42               | 0.368               | 0.000               |
| +5.1668                    | 1.260                | -0.302               |                      |                      |                                | 7.24               | 1.220               | 0.000               |
| 96511                      |                      |                      |                      |                      |                                | 6.62               | 0.225               | 0.000               |
| 114092                     | 0.955                | 0.145                | 1.307                | 1.200                | 0.372                          | 5.51               | 0.430               | 0.015               |
| 120323                     | 1.251                | -0.377               |                      |                      |                                | 2.50               | 1.462               | 0.020               |
| 157881                     | 0.915                | 0.091                | 1.171                | 1.428                | 0.332                          | 6.08               | 0.600               | 0.000               |
| 181480                     |                      |                      | 1.317                | 1.266                | 0.360                          | 5.90               | 0.468               | 0.061               |
| 194640                     | 0.443                | -0.325               | 1.053                | 0.738                | 0.140                          | 6.10               | 0.245               | 0.000               |
| 203875                     | 0.007                | -0.477               |                      |                      |                                |                    |                     | 0.000               |
| 210277                     | 0.468                | -0.285               | 1.058                | 0.766                | 0.191                          | 6.05               | 0.245               | 0.000               |
| 213042                     | 0.688                | 0.042                | 1.131                | 1.176                | 0.262                          | 6.71               | 0.376               | 0.000               |
| <b>Table 6</b>             |                      |                      |                      |                      |                                |                    |                     |                     |
| 55                         | 0.673                | -0.007               |                      |                      |                                | 7.44               | 0.425               | 0.000               |
| 2140                       |                      |                      | 1.304                | 1.133                | 0.343                          | 6.14               | 0.457               | 0.016               |
| 9312                       |                      |                      | 1.125                | 0.880                | 0.248                          | 6.20               | 0.280               | 0.000               |
| 12235                      | 0.349                | -0.379               | 1.003                | 0.611                | 0.152                          | 5.52               | 0.190               | 0.000               |
| 13403                      |                      |                      |                      |                      |                                |                    |                     | 0.000               |
| 13825                      |                      |                      | 1.024                | 0.714                | 0.185                          |                    |                     | 0.000               |
| 13997                      |                      |                      | 1.058                | 0.769                | 0.254                          |                    |                     | 0.000               |
| 15590                      |                      |                      | 1.018                | 0.645                | 0.158                          | 7.58               | 0.220               | 0.000               |
| 17660                      | 0.745                | 0.103                |                      |                      |                                | 7.83               | 0.446               | 0.000               |
| 19305                      | 0.955                | 0.072                |                      |                      |                                | 7.57               | 0.630               | 0.000               |
| 22403                      |                      |                      | 1.040                | 0.643                | 0.092                          | 6.85               | 0.245               | 0.000               |
| 28479                      | 0.803                | 0.034                | 1.246                | 1.039                | 0.352                          | 4.92               | 0.365               | 0.035               |
| +18.683                    | 1.158                | -0.156               |                      |                      |                                | 7.89               | 0.965               | 0.000               |
| 33042                      | 1.083                | 0.198                |                      |                      |                                | 3.4V               | 0.589               | 0.030               |
| 36395                      | 1.094                | -0.083               | 1.230                | 1.407                | 0.012                          | 6.05               | 0.850               | 0.000               |
| +62.780                    |                      |                      |                      |                      |                                | 7.47               | 0.630               | 0.000               |
| 38358                      |                      |                      | 1.290                | 1.162                | 0.373                          |                    |                     | 0.060               |
| 40020                      | 0.757                | -0.051               | 1.222                | 0.942                | 0.306                          | 4.98               | 0.359               | 0.011               |
| 40176                      | 0.732                | -0.045               | 1.233                | 0.880                | 0.318                          | 4.11               | 0.360               | 0.000               |
| 43429                      | 0.710                | -0.095               | 1.184                | 0.933                | 0.250                          | 5.15               | 0.359               | 0.000               |
| 45067                      | 0.321                | -0.447               | 0.995                | 0.560                | 0.109                          | 5.53               | 0.195               | 0.000               |
| <b>Table 7 (continued)</b> |                      |                      |                      |                      |                                |                    |                     |                     |
| 65953                      | 1.063                | 0.153                | 1.251                | 1.279                | 0.424                          | 3.31               | 0.544               | 0.033               |
| +10.1857AB                 | 1.030                | 0.015                |                      |                      |                                | 7.94               | 0.740               | 0.000               |
| C                          |                      |                      |                      |                      |                                | 8.57               | 1.025               | 0.000               |
| +81.297                    | 0.765                | 0.078                |                      |                      |                                | 8.08               | 0.465               | 0.000               |
| 84035                      | 0.715                | 0.071                |                      |                      |                                | 7.05               | 0.405               | 0.000               |
| 90711                      |                      |                      | 1.057                | 0.802                | 0.252                          | 7.26               | 0.279               | 0.000               |
| 97457                      |                      |                      | 1.053                | 0.782                | 0.234                          | (9.90)             | 0.242               | 0.000               |
| 106569                     | 0.328                | -0.424               | 0.993                | 0.581                | 0.127                          | 6.50               | 0.170               | 0.000               |
| 107325                     | 0.727                | -0.054               | 1.199                | 0.974                | 0.300                          | 4.63               | 0.365               | 0.000               |
| 108846                     | 0.234                | -0.481               |                      |                      |                                |                    |                     | 0.000               |
| 112164                     | 0.362                | -0.369               | 1.000                | 0.616                | 0.183                          |                    |                     | 0.000               |
| 117267                     | 0.736                | -0.048               | 1.225                | 0.913                | 0.342                          | 5.50               | 0.350               | 0.020               |
| 118742AB                   |                      |                      |                      |                      |                                |                    |                     | 0.000               |
| C                          |                      |                      |                      |                      |                                |                    |                     | 0.000               |
| 119217                     | 0.880                | 0.093                |                      |                      |                                | 8.34               | 0.555               | 0.000               |
| -44.8976                   |                      |                      |                      |                      |                                | 9.11               | 0.270               | 0.000               |
| 122443                     |                      |                      |                      |                      |                                |                    |                     | 0.020               |
| +30.2512                   | 0.838                | 0.096                |                      |                      |                                | 7.20               | 0.515               | 0.000               |
| 126583                     | 0.460                | -0.303               |                      |                      |                                | 7.48               | 0.240               | 0.000               |
| 132345                     | 0.843                | 0.063                | 1.280                | 1.039                | 0.406                          | 4.65               | 0.398               | 0.040               |
| 136834                     | 0.622                | -0.061               | 1.121                | 1.024                | 0.334                          | 7.52               | 0.334               | 0.000               |
| 139997                     | 1.135                | 0.177                |                      |                      |                                | 3.10               | 0.660               | 0.040               |
| 141477                     | 1.194                | 0.160                | 1.384                | 1.383                | 0.239                          | 2.40               | 0.698               | 0.040               |
| 146388                     |                      |                      | 1.216                | 0.946                | 0.286                          | 4.82               | 0.370               | 0.006               |
| 158633                     | 0.472                | -0.322               |                      |                      |                                |                    |                     | 0.000               |
| 159809                     | 0.654                | -0.122               | 1.157                | 0.915                | 0.269                          | 6.72               | 0.324               | 0.000               |
| 164326                     |                      |                      | 1.022                | 0.678                | 0.189                          |                    |                     | 0.000               |
| 166796                     |                      |                      | 1.169                | 0.941                | 0.320                          |                    |                     | 0.000               |
| 167576                     | 0.868                | 0.046                | 1.274                | 1.053                | 0.362                          | 5.51               | 0.395               | 0.049               |
| 178445                     | 0.879                | 0.132                | 1.171                | 1.427                | 0.355                          | 8.05               | 0.555               | 0.000               |
| 183955                     |                      |                      |                      |                      |                                | 4.14               | 0.630               | 0.075               |
| 191584                     | 0.847                | 0.039                | 1.264                | 1.046                | 0.359                          | 5.19               | 0.370               | 0.040               |
| 206097                     |                      |                      | 1.084                | 0.842                | 0.248                          | 9.14               | 0.276               | 0.000               |
| 215704                     | 0.496                | -0.252               |                      |                      |                                | 7.31               | 0.265               | 0.000               |
| 219263                     | 0.769                | -0.001               | 1.225                | 1.009                | 0.331                          | 4.78               | 0.386               | 0.020               |
| 222013                     | 0.507                | -0.247               | 1.070                | 0.879                | 0.258                          | 8.65               | 0.260               | 0.000               |
| 222804                     |                      |                      | 1.247                | 1.011                | 0.373                          | 5.87               | 0.342               | 0.040               |

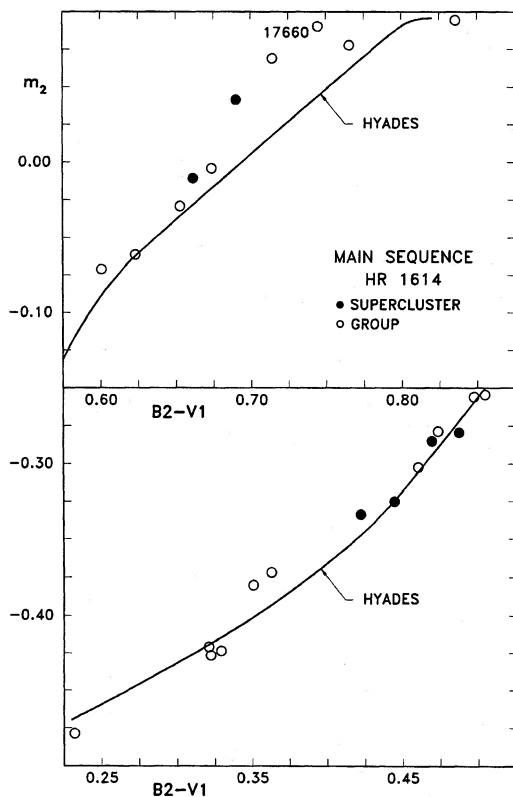


FIG. 8. Metallicity of HR 1614 supercluster and group main sequence members.

from models with  $(Y, Z) = (0.20, 0.01)$  (Green *et al.* 1987). Additional photometry for member stars is listed in Table 10.

The metallicity parameters from the Geneva photometry are compared in Fig. 4 with those of members of the Hyades and Sirius superclusters and they indicate a value of  $[Fe/H] \sim -0.5$  dex (Eggen 1986). McWilliam (1990) found  $[Fe/H] = -0.6 \pm 0.14$  dex for Arcturus (HD 124897). The CN strengths,  $(C_m)_0$ , are compared with those of members of the Hyades and Sirius superclusters in Fig. 5, where they support the relative heavy element abundances shown in Fig. 4.

The distribution of the stars is shown in the  $(X, Y)$  and  $(Z, Y)$  planes of Fig. 16, where the majority of the group members trail the sun in the direction of galactic rotation ( $Y$ ). The distribution of the stars in  $(U, W)$  velocity space is

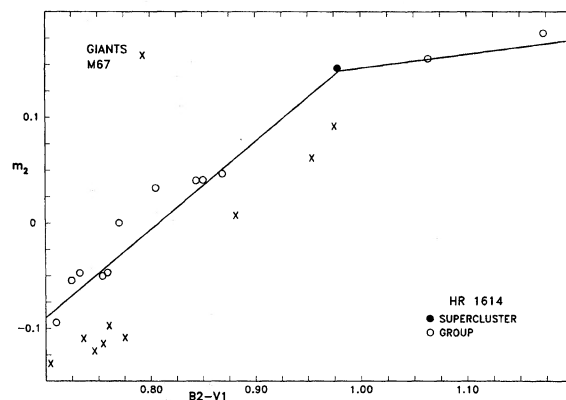


FIG. 9. Metallicity of HR 1614 supercluster and group giant members.

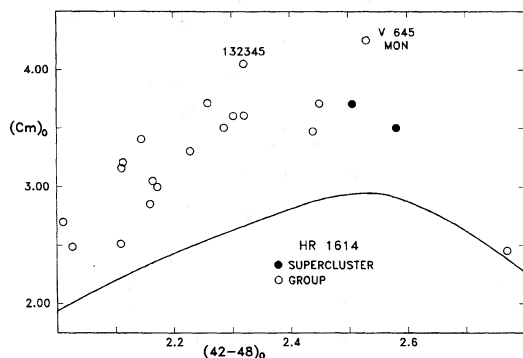


FIG. 10. CN strengths of HR 1614 supercluster and group giant members.

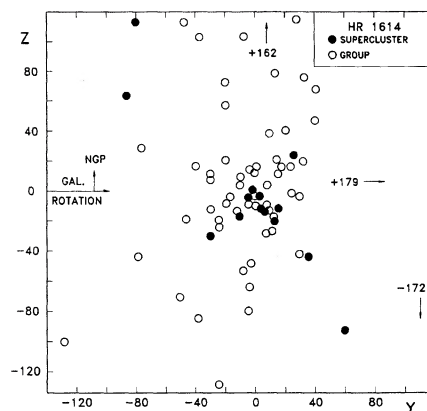
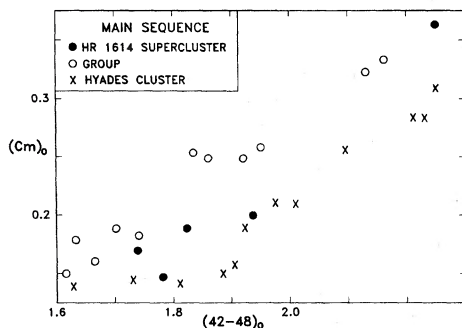
FIG. 13. Distribution of the HR 1614 supercluster and group members in the  $(Y, Z)$  plane.

FIG. 11. CN strengths of HR 1614 supercluster and group dwarf members.

TABLE 8. Galactic velocities and positions of HR 1614 supercluster members.

| HD<br>BD | MOD               | U         | V         | W         | X    | Y   | Z    |
|----------|-------------------|-----------|-----------|-----------|------|-----|------|
|          |                   | km/sec    |           | parsecs   |      |     |      |
| 12051    | 2 <sup>m</sup> 00 | -7.0      | -59.2     | -12.2     | +17  | +15 | -12  |
| 17215    | 3.25              | -3.7      | -59.3     | -11.4     | -12  | -30 | -30  |
| +2.816   | 2.90              | -6.0      | -60.4     | -10.5     | +33  | -10 | -15  |
| 32147    | -0.07             | -6.4      | -59.5     | -11.7     | +8   | -4  | -4   |
| +5.1165  | -2.53             | -5.1      | -59.2     | -12.7     | +3   | -2  | +1   |
| 96511    | 3.00              | -6.6      | -59.7     | -9.5      | +20  | +26 | +23  |
| 114092   | 6.10              | -1.1      | -60.7     | -14.1     | -8   | +7  | +162 |
| 115467   | 5.96              | -9.7      | -56.8     | -12.2     | -71  | -79 | +114 |
| 120323   | 5.71              | -8.0      | -56.5     | -12.9     | -89  | -86 | +63  |
| 157881   | -0.22             | -5.4      | -59.6     | -9.7      | -8   | +4  | -3   |
| 181480   | 7.39              | -7.0      | -53.1     | -3.9      | -280 | +60 | -91  |
| 194640   | 1.93              | -4.9      | -58.8     | -11.4     | -20  | +4  | -13  |
| 203875   | 4.20              | -5.8      | -58.4     | -10.2     | -40  | +37 | -43  |
| 210277   | 2.06              | -6.7      | -59.7     | -9.5      | -11  | +14 | -19  |
| 213042   | 0.89              | -3.4      | -59.3     | -11.8     | -7   | +3  | -13  |
| mean     |                   | -5.8      | -59.6     | -11.4     |      |     |      |
| $\sigma$ |                   | $\pm 2.0$ | $\pm 2.0$ | $\pm 2.0$ |      |     |      |

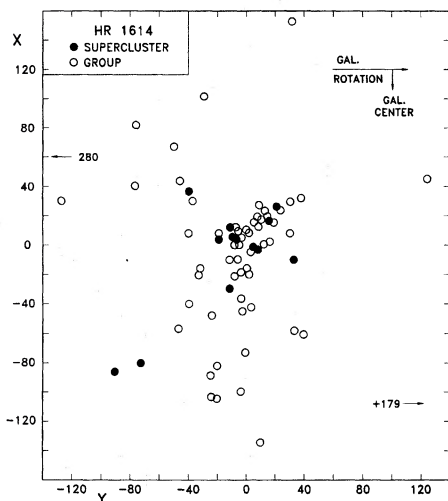
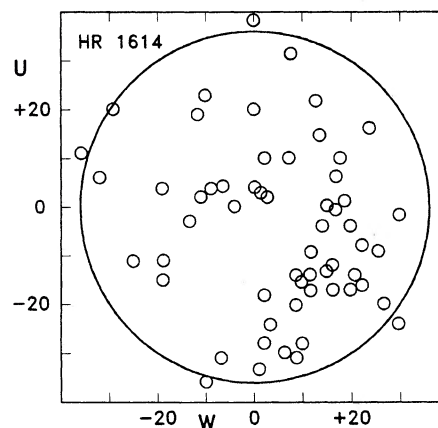
FIG. 12. CN strengths of HR 1614 supercluster and group members in the  $(X, Y)$  plane.FIG. 14. HR 1614 group stars in  $(U, W)$  velocity space.

TABLE 9. Members of the Arcturus group.

| HD       | $\mu_\alpha/\mu_\delta$<br>0''001 | $\rho$<br>km/sec | MOD               | X<br>pc | U   | V<br>km/sec | W    | $V_0$             | (B-V) <sub>0</sub> | Clus               | $M_V$              | Photo | Sp.T.    | Y<br>pc | Z<br>pc | Name      | Note |
|----------|-----------------------------------|------------------|-------------------|---------|-----|-------------|------|-------------------|--------------------|--------------------|--------------------|-------|----------|---------|---------|-----------|------|
| 3266A    | 183/-415                          | -60.6            | 3 <sup>h</sup> 50 | 20      | -17 | -110.5      | -5.3 | 8 <sup>m</sup> 43 | 0 <sup>m</sup> 66  | +4 <sup>m</sup> 93 |                    |       | G3 V     | -37     | -27     | G69-4A    | X    |
| AD54978  |                                   | -59.0            |                   |         |     |             |      | 9.25              | 0.69               | +5.75              |                    |       | G5 V     |         |         | G69-4B    | X    |
| 673A     | 144/-122                          | +95.4            | 3.02              | 13      | -48 | -110        | +43  | 6.45              | 0.855              | +3.43              | +3 <sup>m</sup> 71 |       | G8 IV    | +15     | -35     | +1.212    |      |
| -10.249  | 109/-197                          | -25.0            | 5.04              | 25      | -14 | -110.5      | 0    | 10.89             | 0.72               | +5.85              |                    |       | G5 V     | +20     | -37     | G270-183  |      |
| 10785    | 288/-174                          | -6.9             | 4.34              | 21      | +39 | -110.5      | +15  | 8.51              | 0.605              | +4.17              |                    |       | G1/2 V   | +3      | -71     | -16.301   |      |
| +33.529  | 968/-965                          | -47.5            | 0.98              | 12      | +2  | -110.5      | -8   | 9.58              |                    | +8.60              | +4.35              |       | M0       | +7      | -6      | G37-8     | X    |
| 19735    | 74/-83                            | -36.1            | 6.71              | 180     | +28 | -114.5      | -28  | 6.12              | 1.37               | -0.59              |                    |       | M0       | +121    | -33     | HR 949    |      |
| 21543    | 339/-192                          | +66.0            | 3.78              | 38      | +62 | -111        | -15  | 8.24              | 0.62               | +4.46              | +4.55              |       | G2 V     | -7      | -42     | G77-54    |      |
| 24616    | 333/-299                          | +98.2            | 2.81              | 19      | +36 | -110.5      | -47  | 6.70              | 0.815              | +3.89              |                    |       | G8 IV/V  | -15     | -28     | -23.1619  |      |
| 62301    | 327/-689                          | -5.8             | 2.70              | 31      | +5  | -111        | -24  | 6.76              | 0.54               | +4.06              | +3.92              |       | F8 V     | 0       | +16     | +39.1998  |      |
| 65583    | -170/-1164                        | +14.7            | 1.47              | 17      | -2  | -110.5      | -10  | 7.00              | 0.70               | +5.53              | +5.75              |       | G8 V     | -4      | +9      | +29.1664  |      |
| +20.2421 | -128/-212                         | +32.8            | 4.08              | 34      | +1  | -111        | -62  | 8.37              | 0.87               | +3.21              |                    |       | G8 IV    | -52     | +67     | +13.2079  | X    |
| +48.1829 | -71/-334                          | -10.8            | 0.92              | 9       | -26 | -110.5      | -16  | 10.07             | 1.37               | +9.15              |                    |       | K2       | -23     | +51     | G42-34    |      |
| 90508    | 83/-879                           | -7.5             | 2.22              | 15      | -24 | -110.5      | -21  | 6.42              | 0.60               | +4.20              |                    |       | M2       | +2      | +12     | G144-6    | X    |
| 94518    | -112/-328                         | +92.5            | 3.03              | -3      | -22 | -110        | -20  | 8.35              | 0.61               | +5.32              |                    |       | G1 V     | +4      | +23     | HR 4098   | X    |
| 102212   | -18/-184                          | +50.7            | 5.40              | 7       | -38 | -110        | -20  | 4.00              | 1.51               | -1.40              |                    |       | G2 V     | +36     | +17     | -30.8807  |      |
| 104556   | -346/-510                         | -13.1            | 2.88              | 11      | +14 | -110        | 0    | 6.64              | 0.85               | +3.76              |                    |       | M0 III   | -52     | +108    | HR 4517   |      |
| 108754   | -330/-556                         | +0.7             | 3.06              | -8      | +4  | -110        | -59  | 9.00              | 0.71               | +5.94              |                    |       | G8 V     | +6      | +36     | G122-66   |      |
| 121849   | -460/-299                         | +62.0            | 2.76              | -24     | +11 | -109.5      | +13  | 8.17              | 0.69               | +5.41              |                    |       | G8 V     | +19     | +35     | G13-43    | X    |
| 124897   | -1112/-1995                       | -5.0             | 0.12              | -4      | -25 | -110        | -14  | -0.05             | 1.23               | -0.17              | -0.35              |       | G5 V     | -21     | +16     | -33.9467  |      |
| G166-57  | -695/-1169                        | +7.7             | 1.42              | -6      | -45 | -110        | +37  | 11.10             | 1.32               | +9.68              |                    |       | K2 IIIp  | +1      | +10     | HR 5340   | X    |
| 134088   | -158/-447                         | -59.0            | 3.75              | -42     | +20 | -109        | -84  | 8.00              | 0.59               | +4.25              |                    |       | G2 V     | -6      | +37     | G151-28   |      |
| 145417   | -870/-1424                        | +9.6             | 1.10              | -14     | +62 | -110        | -36  | 7.52              | 0.84               | +6.42              |                    |       | K0 V     | -9      | -1      | -57.6303  | X    |
| 149161   | -180/-77                          | +3.1             | 5.70              | -99     | -5  | -107.5      | +70  | 4.76              | 1.47               | -0.94              |                    |       | G0 V     | +51     | +81     | HR 6159   |      |
| 153075   | -162/-301                         | +99.0            | 3.28              | -39     | -50 | -109        | -29  | 6.99              | 0.56               | +3.71              | +3.60              |       | G5 IV    | -21     | -7      | -52.8215  |      |
| 153334   | -334/-56                          | -89.7            | 3.01              | 1       | -1  | -110        | -4   | 7.06              | 0.67               | +4.05              |                    |       | G0/1 III | -17     | -17     | G226-36   |      |
| 176021   | -247/-268                         | +106.2           | 3.03              | -31     | -68 | -109        | -13  | 7.60              | 0.58               | +4.47              | Note               |       | G0 V     | +22     | -8      | -65.3763  |      |
| 177758   | -178/-415                         | 0.0              | 3.71              | -50     | -47 | -108.5      | -6   | 7.24              | 0.57               | +3.53              |                    |       | G1 V     | +5      | -21     | -12.5278  |      |
| 181720   | 96/-412                           | -54.3            | 3.92              | -57     | +64 | -108.5      | -44  | 7.98              | 0.54               | +4.06              |                    |       | G2 III   | +155    | -27     | -3314164  |      |
| 196866   | -32/-112                          | -78.0            | 6.14              | -61     | -51 | -108.5      | -20  | 6.61              | 1.18               | +0.47              | +0.69              |       | G0 V     | -1      | -15     | +25.4312  |      |
| 199288   | -511/-979                         | -11.0            | 1.83              | -17     | -21 | -110        | +49  | 6.52              | 0.60               | +4.64              |                    |       | G0 V     | -10     | -36     | -44.14214 |      |
| 208998   | 48/-513                           | -20.0            | 3.39              | -30     | +24 | -109        | +37  | 7.12              | 0.58               | +3.73              |                    |       | G8 V     | -17     | -41     | -53.9029  |      |
| 213415   | 253/-362                          | +33.2            | 3.63              | -30     | +33 | -109.5      | -55  | 4.22              | 1.55               | +6.10              |                    |       | G5       | +66     | -115    | -59.7808  |      |
| 219215   | 41/-196                           | -0.4             | 5.64              | -22     | -35 | -110        | +5   | 9.74              | 0.79               | +6.28              |                    |       | G2 V     | +41     | -30     | HR 8834   |      |
| +20.5292 | 100/-222                          | -94.0            | 3.53              | 3       | -11 | -110        | +61  | 6.86              | 0.59               | +4.75              |                    |       | G2 V     | +22     | -13     | G68-3     |      |
| 221830   | 547/253                           | -112.0           | 2.11              | 6       | +49 | -110        |      |                   |                    |                    |                    |       |          |         |         | +30.4982  |      |

Notes to TABLE 9.

6 arcsec separation. A is Sp.B.,  $P = 36.0d$ .  
 The cluster parallax is 0.064 arcsec and the trigonometric is 0.066 arcsec.  
 The cluster parallax is 0.051 arcsec and the trigonometric is 0.053 arcsec.  
 The cluster parallax is 0.065 arcsec and the trigonometric is 0.060 arcsec.  
 The cluster parallax is 0.036 arcsec and the trigonometric is 0.050 arcsec.  
 Sp.B.,  $P = 25.9d$ .  
 Arcturus.  
 The cluster parallax is 0.060 arcsec and the trigonometric is 0.066 arcsec.  
 Sneden and Bond (1976) call this object a subgiant CH star and find  $M_V \sim +4$  mag with enhanced carbon and s-process elements.  
 They concluded that it is highly evolved, having recently returned to the vicinity of the main sequence as a result of extensive internal mixing.

HD 3266AB  
 +33.529  
 HD 65583  
 +48.1829  
 HD 90508  
 HD 108754  
 HD 124897  
 HD 145417  
 HD 176021

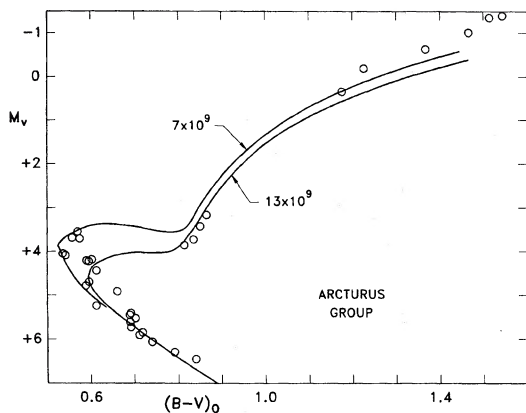


FIG. 15. Color-luminosity array for the Arcturus group.

seen in Fig. 17 where the radius of the tube of disrupted orbits is twice ( $\sim 70$  km/s) that of the HR 1614 group members (Fig. 14).

### 3.3 Kapteyn's Star Group

The most certain members of Kapteyn's star group are listed in Table 11. Most of the proper motions are from Carlsberg meridian circle catalogues (e.g., Carlsberg 1988). The group members are shown in the  $(M_V, B-V)$  plane of Fig. 18 as closed (variables) and open circles. Also, the fiducial sequences of M3 (Sandage 1970) are shown by crosses with a cluster modulus of 14.90 mag and  $E(B-V) = 0.00$  mag. A few blue stragglers, known to be cluster

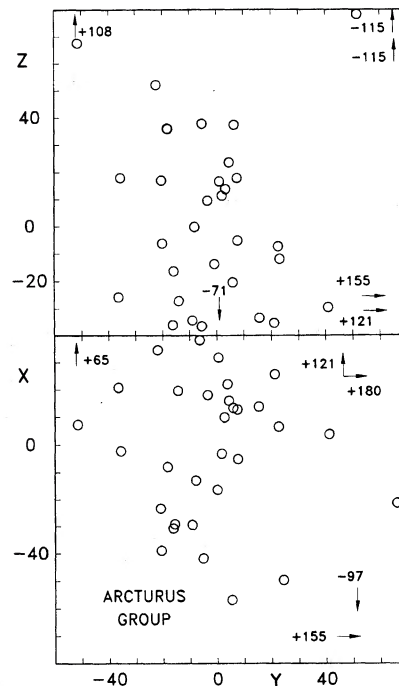


FIG. 16. Spatial distribution of Arcturus group members.

members (e.g., Sandage & Katum 1982) are also represented. The luminosities in Table 11 are based on the cluster parallax from

$$V = -289 - 0.026X \text{ km/s,}$$

where  $X$  is the radial distance (parsecs) from the sun. The agreement with M3 in Fig. 18 is excellent except for a slight displacement of the subgiant and HB stars which may result from a slightly different age and/or metallicity. Table 12 contains additional photometry of the stars in Table 11 and the Geneva photometry ( $B2-V7, d, m_2$ ) is shown in Figs. 19 and 20. The  $d$  parameter is the luminosity indicator in that photometric system and, as seen in Fig. 19, the main sequence, subgiant, and horizontal branch (HB) stars are well

| HD       | (B2-V1) <sub>0</sub> | $m_2$                | (45-48) <sub>0</sub> | (42-45) <sub>0</sub> | (C <sub>m</sub> ) <sub>0</sub> | I <sub>0</sub>     | (R-I) <sub>0</sub>  | E(b-y)              |
|----------|----------------------|----------------------|----------------------|----------------------|--------------------------------|--------------------|---------------------|---------------------|
| 3266A    |                      |                      |                      |                      |                                |                    |                     | 0 <sup>m</sup> .000 |
| ADS497B  |                      |                      |                      |                      |                                |                    |                     | 0.000               |
| 6734     | 0 <sup>m</sup> .561  | -0 <sup>m</sup> .284 | 1 <sup>m</sup> .117  | 0 <sup>m</sup> .785  | 0 <sup>m</sup> .105            | 5 <sup>m</sup> .70 | 0 <sup>m</sup> .325 | 0.000               |
| -10.249  |                      |                      |                      | 1.060                | 0.719                          | 0.069              |                     | 0.000               |
| 10785    | 0.357                | -0.423               | 1.033                | 0.642                | 0.062                          | 8.20               | 0.210               | 0.000               |
| +33.529  | 0.909                | -0.068               |                      |                      |                                |                    |                     | 0.000               |
| 19735    | 1.001                | 0.118                | 1.312                | 1.250                | 0.288                          |                    |                     | 0.040               |
| 21543    | 0.379                | -0.447               | 1.030                | 0.622                | 0.059                          | 7.75               | 0.250               | 0.000               |
| 24616    |                      |                      | 1.100                | 0.752                | 0.060                          | 5.99               | 0.300               | 0.000               |
| 62301    | 0.311                | -0.499               |                      |                      |                                |                    |                     | 0.000               |
| 65583    | 0.451                | -0.370               | 1.059                | 0.719                | 0.080                          | 6.58               | 0.275               | 0.000               |
| 80811    |                      |                      | 1.115                | 0.778                | 0.095                          | 7.70               | 0.316               | 0.010               |
| +48.1829 | 1.014                | -0.113               |                      |                      |                                | 8.25               | 0.820               | 0.000               |
| 90508    | 0.367                | -0.439               | 1.017                | 0.619                | 0.099                          | 5.96               | 0.235               | 0.000               |
| 94518    | 0.366                | -0.469               | 1.029                | 0.596                | 0.060                          | 7.92               | 0.213               | 0.000               |
| 102212   | 1.134                | 0.117                | 1.357                | 1.297                | 0.179                          | 2.30               | 0.735               | 0.000               |
| 104556   | 0.562                | -0.283               | 1.120                | 0.789                | 0.065                          |                    |                     | 0.000               |
| 108754   | 0.430                | -0.384               | 1.063                | 0.713                | 0.050                          | 8.41               | 0.262               | 0.000               |
| 121849   | 0.427                | -0.388               | 1.050                | 0.691                | 0.077                          | 7.61               | 0.237               | 0.000               |
| 124897   | 0.882                | -0.052               | 1.277                | 1.026                | 0.158                          | -1.12              | 0.420               | 0.000               |
| G166-57  |                      |                      |                      |                      |                                | 9.55               | 0.630               | 0.000               |
| 134088   | 0.364                | -0.482               |                      |                      |                                | 7.61               | 0.210               | 0.000               |
| 145417   | 0.520                | -0.302               | 1.092                | 0.785                | 0.090                          | 6.98               | 0.330               | 0.000               |
| 149161   | 1.077                | 0.169                | 1.350                | 1.315                | 0.263                          | 3.38               | 0.621               | 0.020               |
| 153075   | 0.352                | -0.470               | 1.018                | 0.593                | 0.078                          | 6.54               | 0.225               | 0.000               |
| 153334   | 0.409                | -0.376               |                      |                      |                                | 6.60               | 0.22                | 0.000               |
| 176021   | 0.379                | -0.470               | 1.025                | 0.626                | 0.084                          | 7.19               | 0.198               | 0.000               |
| 177758   | 0.342                | -0.484               | 1.011                | 0.575                | 0.077                          | 6.80               | 0.230               | 0.000               |
| 181720   | 0.361                | -0.463               | 1.016                | 0.591                | 0.076                          |                    |                     | 0.000               |
| 196866   | 0.918                | -0.022               | 1.268                | 1.655                | 0.189                          | 5.67               | 0.395               | 0.082               |
| 199288   | 0.359                | -0.475               | 1.011                | 0.596                | 0.080                          | 6.14               | 0.223               | 0.000               |
| 208998   | 0.356                | -0.455               | 1.007                | 0.581                | 0.088                          | 6.71               | 0.205               | 0.000               |
| 213415   | 0.471                | -0.332               | 1.071                | 0.769                | 0.091                          | 9.14               | 0.275               | 0.000               |
| 219215   | 1.168                | 0.162                | 1.353                | 1.401                | 0.269                          | 2.47               | 0.805               | 0.000               |
| +20.5292 |                      |                      |                      |                      |                                |                    |                     | 0.000               |
| 221830   | 0.365                | -0.438               | 1.024                | 0.599                | 0.067                          | 6.36               | 0.245               | 0.000               |

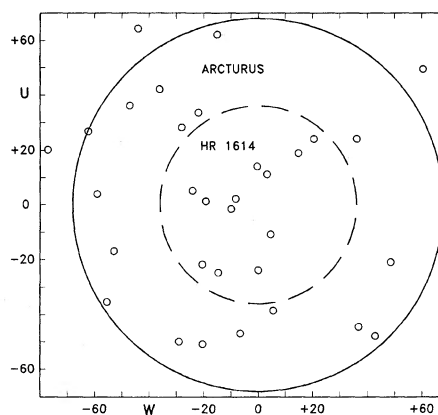
FIG. 17. Arcturus group members in  $(U, W)$  velocity space.

TABLE 11. Members of Kapteyn's stars group.

| HD<br>(Name) | $\mu_\alpha/\mu_\delta$<br>0.001 | $\rho$<br>km/sec | X<br>pc | MOD       | U    | V<br>km/sec | W    | $V_0$     | (B-V) <sub>0</sub> | $M_V$  | Y    | Z<br>pc | Sp.T.   | Name      | Note |
|--------------|----------------------------------|------------------|---------|-----------|------|-------------|------|-----------|--------------------|--------|------|---------|---------|-----------|------|
| 13979        | 31/-63                           | +60.7            | 235     | $q^{m76}$ | -70  | -295        | -28  | $q^{m16}$ | 0.79               | -0.60  | -158 | -849    | F7/6 W  | -28.814   |      |
| -30.1121     | 31/-36                           | +103.9           | 391     | 10.48     | -19  | -299        | -10  | 10.30     | 0.73               | -0.18  | -422 | -1109   | G       |           |      |
| X Ari        | 66/-89                           | -36.9            | 430     | 8.78      | -15  | -300        | -28  | 9.07      | 0.30               | +0.29  | +83  | -365    | A5      | +9.398    | X    |
| 21022        | 34/-36                           | +110.0           | 395     | 10.37     | -26  | -299        | +13  | 9.19      | 0.95               | -1.18  | -513 | -842    | G6/5 W  | -33.1191  |      |
| G38-1        | 1122/-985                        | +173.0           | 29      | 2.64      | -52  | -289.5      | +23  | 11.11     | 1.32               | +8.47  | +14  | -9      | K5      | R 34      |      |
| 25532        | 87/-114                          | -112.5           | 384     | 8.11      | -68  | -289        | +6   | 7.93      | 0.61               | -0.18  | +68  | -154    | g F5    | +22.626   |      |
| 33793        | 6565/-5722                       | +244.0           | 1       | -2.00     | -21  | -289        | -51  | 8.85      | 1.57               | +10.85 | -3   | -2      | M0 V    | -45.1841  | X    |
| -30.8626     | -9/-43                           | +263.0           | -25     | 9.00      | -57  | -288.5      | -5   | 9.66      | 0.75               | +0.65  | -575 | +260    |         |           |      |
| G236-38      | -92/-265                         | -86.9            | 118     | 6.72      | +41  | -292        | +47  | (13.55)   | 0.78               | +6.83  | +98  | +158    |         | W365      | X    |
| G10-4        | -586/-543                        | +62.1            | -16     | 4.68      | +116 | -289        | -118 | 11.40     | 0.72               | +6.72  | -42  | +74     | sd G3   | +68.652   | X    |
| SU Dra       | -481/-76                         | -175.0           | 263     | 8.80      | +1   | -299        | -41  | 9.85      | 0.285              | +1.05  | +274 | +431    | A5      | -43155    | X    |
| ST Leo       | -15/-42                          | +150.0           | 142     | 10.46     | -25  | -293        | +79  | 11.29     | 0.175              | +0.83  | -478 | +1131   | A5      | G13-9     | X    |
| -4.3208      | -281/-227                        | +61.5            | -23     | 6.37      | +115 | -288.5      | -104 | 10.00     | 0.40               | +3.63  | -104 | +154    | sd F0   | -12.3709  |      |
| 110621       | -226/-14                         | +221.0           | -92     | 6.33      | +55  | -287.5      | +52  | 7.85      | 0.445              | +3.52  | -149 | +58     | G6 V    | W449      |      |
| 111721       | -270/-320                        | 23.5             | -58     | 6.11      | +64  | -287.5      | -147 | 7.85      | 0.765              | +1.74  | -91  | +127    | G6 V    | -43.5866  |      |
| G60-48       | -276/-249                        | 6.2              | -27     | 6.17      | +79  | -288.5      | -41  | 11.39     | 0.495              | +5.17  | -34  | +166    | sd F4   | LHS 2872  |      |
| -13.3834     | -330/-476                        | 123.7            | -60     | 4.95      | -47  | -287.5      | -11  | 10.62     | 0.58               | +5.67  | -35  | +68     | sd G5   | -26.10505 |      |
| 130095       | -212/-82                         | 62.5             | -219    | 7.25      | +110 | -283.5      | +74  | 7.94      | 0.05               | +0.69  | -115 | +139    | A0 V    | +25.3344  |      |
| 161817       | -38/-42                          | -364.0           | -98     | 6.15      | +182 | -286.5      | -36  | 6.97      | 0.14               | +0.82  | +97  | -86     | G0/3 W  | -45.9704  |      |
| 181007       | -46/-177                         | -7.0             | -311    | 7.64      | -67  | -281        | -141 | 9.24      | 0.715              | +1.60  | +71  | -31     | F3/5 W  |           |      |
| 181743       | -80/-820                         | 21.0             | -68     | 4.37      | +36  | -287        | -54  | 9.65      | 0.46               | +5.28  | -8   | +4      | K2 III  | -42.8943  |      |
| G185-30      | -82/-387                         | -236.2           | -51     | 4.98      | -33  | -288.5      | -69  | 12.55     | 1.03               | +7.57  | +85  | +42     | F0 V    |           |      |
| 186478       | -24/-90                          | +25 V:           | -535    | 9.31      | -53  | -2755       | -160 | 8.85      | 0.85               | -0.96  | -220 | -72     | sd F0   | -20.5895  |      |
| 188031       | 10/-433                          | -144.5           | -129    | 5.85      | +174 | -286        | +74  | 10.44     | 0.445              | +3.83  | +143 | -52     | G8 W F3 | -30.18898 |      |
| G24-3        | -123/-170                        | -209.2           | -143    | 6.61      | -9   | -285.5      | +15  | 9.84      | 0.71               | +2.25  | +46  | -307    | G K W   |           |      |
| 193242       | -18/-98                          | -128.4           | -424    | 8.61      | +25  | -278        | +4   | 9.10      | 0.775              | +0.49  | +88  | -191    | G5 W F0 | -32.17234 |      |
| -62.1346     | -23/-111                         | 127.0            | -333    | 8.42      | -53  | -281.5      | +8   | 9.20      | 0.78               | +5.08  | +85  | -93     | G6 W F3 | -46.10449 |      |
| 208069       | 144/-207                         | -166.7           | -147    | 6.95      | +179 | -289        | +8   | 8.39      | 0.78               | +3.24  | +46  | -335    | F0 W    | G28-43    |      |
| G18-54       | 57/-327                          | -205.0           | -33     | 5.58      | -18  | -288        | +30  | 10.66     | 0.465              | +0.70  | +31  | -42     | sd G2   | SX Phe    | X    |
| 215601       | 62/-144                          | -42.5            | -168    | 7.90      | +37  | -284.5      | -9   | 9.99      | 0.39               | +6.35  | +7   | -65     | A3 V    |           |      |
| 215801       | 33/-313                          | -87.0            | -112    | 6.75      | +14  | -286        | +139 | 9.97      | 0.70               | +3.05  | +7   | -65     |         |           |      |
| -0.4470      | -220/-295                        | -112.6           | -7      | 3.62      | -200 | -289        | -38  | 9.97      | 0.70               | +3.05  | +7   | -65     |         |           |      |
| 223065       | 259/-863                         | -29.0            | -22     | 4.20      | -18  | +288.5      | +69  | 7.25      | 0.25               | +3.05  | +7   | -65     |         |           |      |
|              |                                  |                  |         | mean      | +13  | -16         | -16  |           |                    |        |      |         |         |           |      |
|              |                                  |                  |         | $\sigma$  |      | +82         | +6   | +67       |                    |        |      |         |         |           |      |

Notes to TABLE 11.

VSPC (RR Lyr),  $P = 0.65d$ .

Kapteyn's star.

Sp.B.,  $P = 26.7$  d. Equal componentsVSPC (RR Lyr),  $P = 0.66d$ .VSPC (RR Lyr),  $P = 0.48d$ .

Microvariable.

Sp.B., orbit not available.

VSPC (s Sct) 5 X Phe.

X Ari

33793

G236-38

Su Dra

ST Leo

161817

186478

223065

TABLE 12. Additional photometry for Kapteyn's star group.

| HD<br>Name | (B2-V1) <sub>0</sub> | d                  | m <sub>2</sub>     | (45-48) <sub>0</sub> | (42-45) <sub>0</sub> | (C <sub>m</sub> ) <sub>0</sub> | I <sub>0</sub>    | (R-I) <sub>0</sub> | E(b-y)             |
|------------|----------------------|--------------------|--------------------|----------------------|----------------------|--------------------------------|-------------------|--------------------|--------------------|
| 13979      | 0.461                | 0 <sup>m</sup> 913 | 0 <sup>m</sup> 553 | 1 <sup>m</sup> 086   | 0 <sup>m</sup> 493   | -0 <sup>m</sup> 030            | 8 <sup>m</sup> 56 | 0 <sup>m</sup> 321 | 0 <sup>m</sup> 000 |
| -30.1121   | 0.518                | 0.735              | -0.518             | 1.100                | 0.610                | -0.026                         |                   |                    | 0.020              |
| 21022      | 0.684                | 0.877              | -0.432             | 1.200                | 0.671                | -0.101                         | 8.42              | 0.404              | 0.000              |
| G38-1      | 0.948                | 0.291              | -0.060             |                      |                      |                                | 9.62              | 0.600              | 0.000              |
| 25532      | 0.436                | 0.926              | -0.515             | 1.057                | 0.533                | 0.014                          | 7.71              | 0.242              | 0.009              |
| 33793      | 1.192                | 0.247              | -0.089             | 1.313                | 1.584                | 0.069                          | 7.00              | 0.815              | 0.000              |
| -30.8626   | 0.534                | 0.878              | -0.505             | 1.116                | 0.564                | -0.040                         | 8.87              | 0.340              | 0.015              |
| -4.3208    | 0.218                | 0.857              | -0.587             | 0.957                | 0.416                | 0.098                          | 9.60              | 0.200              | 0.000              |
| G10-4      | 0.498                | 0.476              | -0.488             | 1.097                | 0.622                | 0.003                          | 10.73             | 0.320              | 0.000              |
| 110621     | 0.253                | 0.800              | -0.573             | 0.966                | 0.451                | 0.095                          | 9.50              | 0.195              | 0.015              |
| 111721     | 0.507                | 0.638              | -0.457             | 1.106                | 0.675                | -0.006                         | 7.15              | 0.330              | 0.025              |
| G60-48     | 0.296                | 0.688              | -0.569             | 1.004                | 0.472                | 0.045                          |                   |                    | 0.000              |
| -13.3834   | 0.376                | 0.601              | -0.528             | 1.046                | 0.548                | 0.011                          | 10.17             | 0.257              | 0.015              |
| 130095     | -0.119               | 1.664              | -0.572             |                      |                      |                                |                   |                    | 0.040              |
| 161817     | -0.004               | 1.605              | -0.566             |                      |                      |                                |                   |                    | 0.000              |
| 181007     | 0.498                | 0.661              | -0.472             | 1.103                | 0.657                | -0.015                         | 8.54              | 0.305              | 0.080              |
| 181743     | 0.266                | 0.676              | -0.557             | 0.982                | 0.469                | 0.079                          | 9.36              | 0.205              | 0.000              |
| 186478     | 0.625                | 0.852              | -0.485             | 1.154                | 0.623                | -0.120                         | 8.10              | 0.463              | 0.000              |
| 188031     | 0.249                | 0.801              | -0.585             | 0.960                | 0.441                | 0.105                          | 9.69              | 0.212              | 0.015              |
| G24-3      | 0.283                | 0.712              | -0.554             | 0.981                | 0.461                | 0.095                          | 10.05             | 0.207              | 0.010              |
| 193242     | 0.519                | 0.717              | -0.515             | 1.108                | 0.621                | -0.027                         | 8.24              | 0.355              | 0.010              |
| -62.1346   | 0.490                | 0.745              | -0.495             | 1.068                | 0.647                | 0.050                          | 9.15              | 0.290              | 0.000              |
| 208069     | 0.468                | 0.705              | -0.518             | 1.093                | 0.602                | -0.033                         | 8.10              | 0.463              | 0.000              |
| G18-54     | 0.305                | 0.731              | -0.563             | 0.984                | 0.479                | 0.084                          | 10.25             | 0.214              | 0.010              |
| 215601     |                      |                    |                    | 1.133                | 0.642                | -0.038                         | 7.75              | 0.335              | 0.015              |
| 215801     | 0.237                | 0.848              | -0.593             | 0.973                | 0.429                | 0.081                          | 9.63              | 0.196              | 0.015              |
| -0.4470    | 0.464                | 0.474              | -0.439             | 1.066                | 0.673                | 0.001                          | 9.33              | 0.324              | 0.000              |

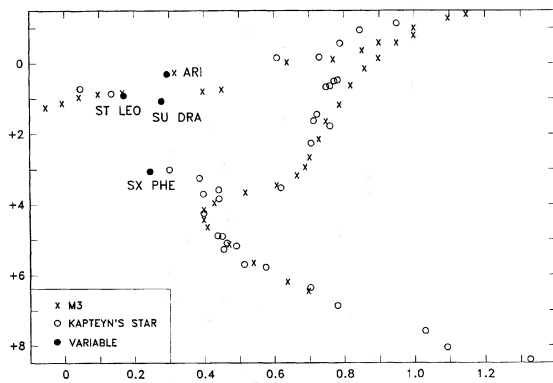


FIG. 18. Color-luminosity array for Kapteyn's star group.

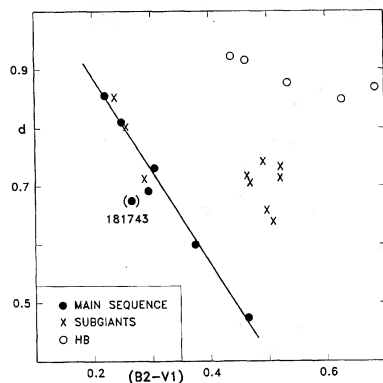


FIG. 19. Luminosity calibration for Kapteyn's star group members.

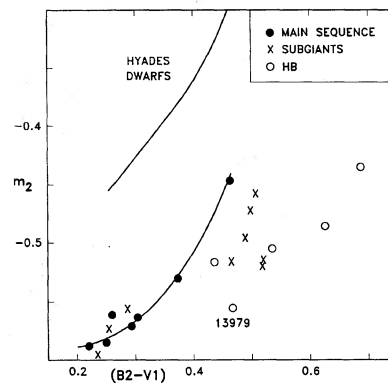


FIG. 20. Metallicity calibration for Kapteyn's star group members.

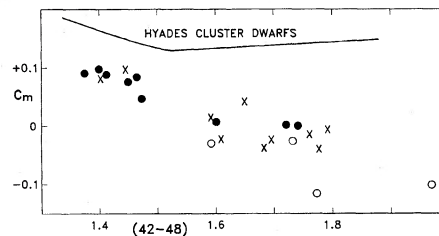


FIG. 21. CN strengths of Kapteyn's star group dwarfs (closed circles), subgiants (crosses), and HB (open circles) members.

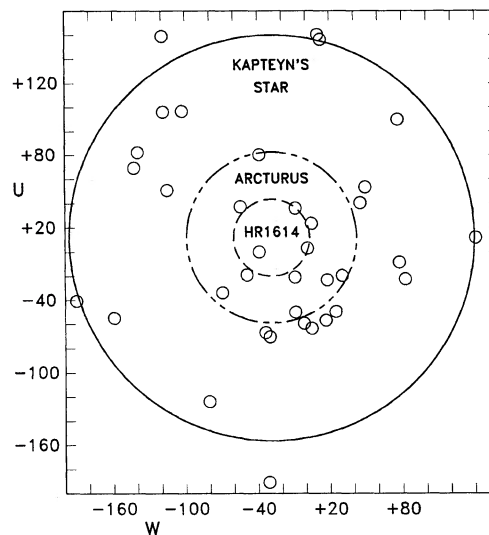


FIG. 22. The distribution of Kapteyn's star group members in (U, W) space.

differentiated. The metallicity parameter,  $m_2$ , is shown in Fig. 20 where the HB and subgiant stars are separated from the main sequence. The main sequence stars show a value of  $\Delta m_2 \sim 0.125$  mag compared with the Hyades dwarfs.

The labeled stars in Figs. 19 and 20 require notice. The Geneva photometry for HD 181743 in Fig. 19 needs to be confirmed because the equivalent diagram ( $[C_1], b-y$ ) of the Strömgen photometric system shows no discrepancy for this star. Also HD 13979, which is displaced in Fig. 20, shows no displacement from the other subgiants in the equivalent diagram, ( $[m_1], b-y$ ) for the Strömgen photometric system. The metallicity of these stars will be discussed in detail elsewhere in connection with the Ross 451 group of halo stars (Eggen 1996a).

The CN strengths,  $C_m$ , are shown in Fig. 21 where the continuous line represents Hyades cluster dwarfs (Fig. 11). Both the giants and dwarfs in the halo population show a distinct difference in CN distribution, compared with disk objects. This effect was noted previously (Eggen 1990, Fig. 3) and discussed on the basis of the differences in the environment at the birth of old disk and halo stars. The fact that this effect is seen in both giants and dwarfs eliminates the possibility that it is of evolutionary origin. The effect also identifies both the Arcturus group and the globular cluster 47 Tuc as old disk aggregates (Eggen 1990, Fig. 4). It is interesting to note that DDO photometry also enables young and old disk stars to be separated (Eggen 1995b). Explanations of these distinguishing features, which may depend on CN and/or CH abundances, will have strong influence in the understanding of galactic structure.

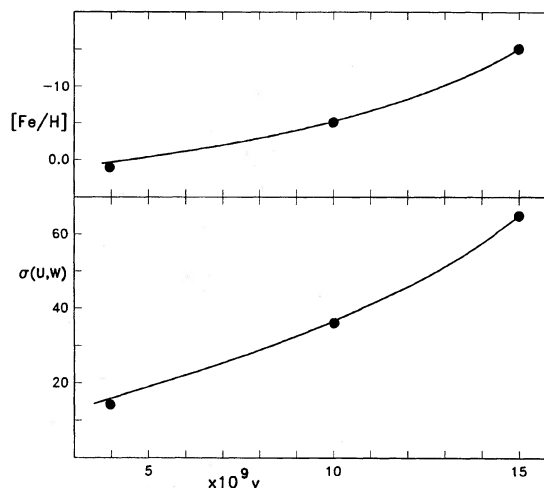


FIG. 23. The dependence on age of the metallicity (upper panel) and dispersion of the  $(U, W)$  velocities (lower panel) for Solar Circle Stream stars.

The distribution of the  $(U, W)$  velocities is shown in Fig. 22, where the cross sections of the HR 1614 group (Fig. 14) and the Arcturus group (Fig. 17) orbit tubes are also represented. The ratios of the radii of these tubes is HR 1614/Arcturus/Kapteyn's star = 35/70/160 and the radii doubles approximately every 5 giga years. The dispersions in the velocities are

| Group          | [Fe/H] | Age<br>(yr.)     | $U$ | $V$    | $W$ | $\sigma(U)$ | $\sigma(V)$ | $\sigma(W)$     |
|----------------|--------|------------------|-----|--------|-----|-------------|-------------|-----------------|
| HR 1614        | +0.1   | $4 \times 10^9$  | +5  | -59.5  | -6  | $\pm 17$    | $\pm 1.5$   | $\pm 14$ km/sec |
| Arcturus       | -0.5   | $10 \times 10^9$ | -9  | -110   | -9  | $\pm 36$    | $\pm 1.0$   | $\pm 36$        |
| Kapteyn's star | -1.5   | $15 \times 10^9$ | +13 | -288.5 | -16 | $\pm 82$    | $\pm 6.0$   | $\pm 67$ .      |

The dispersion in  $V$ , of course, only represents that in  $X$ . The metallicity of the members of Kapteyn's star group is uncertain (e.g., Eggen 1990) but  $[Fe/H] = -1.5$  dex has been adopted here. The dependence of the enrichment of the pre-stellar material and of the dispersion of the  $(U, W)$  velocities, on age is shown in Fig. 23 (e.g., Sandage 1987).

#### 4. SUMMARY

In today's vocabulary of stellar structure, the solar circle stream contains old thin disk (HR 1614), old thick disk (Arcturus), and halo (Kapteyn's star) objects. The material that formed the oldest of these groups presumably was plunging toward what was to become the galactic center, along a path that would become the flattened disk and, although the stars continued on their highly eccentric orbits, the pileup of pre-stellar material caused a circularization of its orbit, reaching  $e \sim 0.5$  some 5 giga years later when the Arcturus group stars were formed and  $e \sim 0.25$  another

6 giga years later when the HR 1614 group stars were produced. It is of some interest that stellar production in the stream apparently ceased after the birth of the uniquely strong CN stars of the HR 1614 group. Young disk stars with  $V \sim 0$  km/s are rare (e.g., Eggen 1994, Fig. 23; 1995b, Fig. 15). An interesting question is the possibility that the unique feature of strong CN in the last epoch of star formation in the stream is connected with the lack of subsequent production.

It can be assumed that events within a stream are influenced by the parameters of the prestellar material. The stars in Stream I (Hyades stream) reached  $[Fe/H] = 0.1$  dex only  $10^9$  yr ago whereas those in Stream 0 (Pleiades), only  $10^8$  yr ago, and in Stream II (UMa), reached solar metallicity only  $5 \times 10^9$  yr ago. Our concept of stellar populations is based on the combined conditions within several streams and more multiple group streams, such as the Solar Circle Stream, are necessary for a clearer view of the situation. The search for such streams is an ongoing project.

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