I. CLUSTERS AND ASSOCIATIONS

(A) INTRODUCTION

Renewed interest in the study of star clusters and associations has been aroused by at least three developments.

(*a*) Interpretation of the color-magnitude (C-M) diagrams of clusters and associations with a theory of stellar evolution promises to give data on galactic structure problems. Information of kinematic relations, origins, and past history of stars over the face of the H-R diagram will be available when proper evolutionary interpretation is achieved. Only by assembling C-M diagrams of many clusters of different ages and richness can the empirical approach to evolution be fully exploited.

(*b*) Clusters and associations are tracers of spiral structure. Modern multi-color photometric methods, developed principally by Becker and by Johnson and Morgan, permit precise determination of distances of clusters. Both Kerr and Oort emphasized the importance of absolute distances in order to calibrate the distance scale of the radio galaxy. If enough clusters and associations are available to define the spiral structure, then the arm spacing and the value of the A constant can be found. This requires accurate, standardized photometry and radial velocity measurements on many clusters.

(*c*) C-M diagrams for clusters provide the most accurate method for finding the absolute magnitudes of luminous O and B stars. When diagrams for OB clusters are determined as faint as the A and F stars, calibration of the OB stars is immediate. When enough cluster diagrams are available, the cosmic dispersion σ about the mean absolute magnitude M_0 will be found. Both M_0 and σ are required for tracing spiral arms by O and B stars in associations.

(B) CLUSTERS AND STELLAR EVOLUTION

Precision C-M diagrams for a few nearby clusters are available principally through the photo-electric work of O. J. Eggen and H. L. Johnson. A composite C-M diagram [1] for all the available clusters shows the following systematic regularities: (*a*) The bright end of the main sequence in different clusters terminates at different absolute magnitudes. (*b*) The slope of the main sequence near the termination points is always steeper than the corresponding slope for clusters with brighter termination points. (*c*) When giants or super-giants are present, the absolute magnitude of the giant or super-giant sequence is nearly the same as that of the main sequence termination point. (*d*) A Hertzsprung gap is present in all clusters whose main sequence termination points are brighter than visual absolute magnitude $M_v = +2{\cdot}5$ but the width of the gap depends on absolute magnitude. These results were known and discussed by Trumpler and have been emphasized by modern work. One interpretation follows from work on stellar evolution by M. Schwarzschild and his school. This group believes that stars with a range of masses contract from the interstellar medium and populate the main sequence over a range of luminosities. After thermonuclear processes convert about 10 % of the H to He in any main sequence star, that star leaves the main sequence, moves rapidly to the right in the H-R diagram on a very short time scale (forming the Hertzsprung gap), then slows down to form the giant and super-giant sequences. The absolute magnitude of the termination point of the main sequence changes with time in any cluster because the massive, luminous stars burn 10 % of their hydrogen and leave the main sequence before the less luminous stars have evolved very far.

Application of this theory gives the ages of any cluster whose main sequence termination luminosity is known. Ages range from 10^6 years for *h* and χ Persei to about 5×10^9 years for clusters like M 67. An interesting consequence of these ideas is the large cosmic dispersion expected in the absolute magnitudes of Morgan and Keenan's luminosity classes. In any given cluster, the dispersion will be small or zero. But, because of the change of slope near the main sequence termination point (item *b* in the listing of the systematic features) stars of the same spectral class near this point will have different absolute magnitudes in clusters of slightly different age. This must be borne in mind in calibration of the Morgan-Keenan luminosity classes for stars in the general field. The same is true for the giant and super-giant stars. Generalization of the composite cluster diagram suggests that a continuous variation of absolute magnitude exists for non-main sequence stars from $M_v = +2$ to $M_v = -6$. Because the MK classification recognizes only the five major non-main sequence classes IV, III, II, Ib and Ia, there will be appreciable cosmic scatter about M_o.

(c) A STANDARDIZED CLUSTER PROGRAM

Precision C-M diagrams for *many* clusters of all ages are needed to guide theoretical workers in stellar evolution, to provide an optical scale for the radio galaxy, and to solve the absolute magnitude calibration problem. The conference participants stressed the extreme importance for all workers in the cluster field to adopt standardized techniques and procedures to insure that photometric data collected in the next few years will be precise and homogeneous. Only in this way can individual results be combined and discussed as a whole. The conference addressed itself to this problem of procedure and discussed two separate sub-problems: (*a*) photometry, proper motion and radial velocity work in clusters already known, and (*b*) discovery of new and more distant clusters. Haffner, in his introductory talk, stressed the lack of detailed knowledge of even the Trumpler class for a large number of known galactic clusters. This is illustrated by means of Table 1, the upper part of which shows the numbers of clusters

Table 1. *Statistics of photometry and spectroscopic classifications available for clusters in Trumpler's catalog*

	North of $-15°$ decl.		South of $-15°$ decl.	
Trumpler type	C-M diagram available	C-M diagram not available	C-M diagram available	C-M diagram not available
o	2	4	2	2
b	15	5	1	19
b–a	6	6	0	8
a	11	9	2	6
f	2	0	0	0
All types	36	24	5	35
Type unknown	25	84	9	117

with known Trumpler type, with and without known C-M diagrams, whereas the bottom line gives the corresponding numbers for the clusters without Trumpler type in Trumpler's catalog. The subdivision according to the northern and southern declinations shows the large deficiency of C-M observations of southern clusters. Haffner urged (*a*) that a co-operative program be undertaken of multi-color photometry for C-M diagrams of most known galactic clusters, and (*b*) that a search program for the discovery of distant clusters be started. The result of such a program would be primarily the optical location and distance calibration of the spiral arms. The time for completion of such a program would be five years. He urged uniformity of photometric technique and suggested adoption of the Johnson U-B-V photometric system and the Johnson-Morgan technique of absorption determination. Additional wave-lengths could be added for special purposes but at least U, B, and V values should be published for each cluster.

The experience of the Hamburg observers with Schmidt plates and modern iris diaphragm photometers shows that high *internal* precision can be obtained for magnitude measures using photographic techniques. The Mount Wilson observers have also had success with large reflector plates measured with a variable iris photometer. The most efficient way to complete the large cluster program therefore seems to be to set up accurate photo-electric scales and zero points near each cluster and then to use photographic interpolation for those clusters with many stars. The conference emphasized the necessity that absolute calibration be done *photo-electrically*. Otherwise the program need not be started because the necessary precision cannot be obtained by photographic transfer methods. The conference discussed at length the needs and procedures for the photo-electric scale and zero-point determinations. A small committee consisting of Haffner, Oosterhoff, Sandage, and Walker (chairman) was appointed to work out details. Their recommendations were approved by the conference and appear in detail in the Appendix. A summary of the conclusions follows:

(*a*) Adopt the U-B-V photometric system of Johnson as the standard to which to refer all instrumental magnitudes.

(*b*) Set up zero-point and photometric scales by photo-electric means in or near each cluster to be studied.

(*c*) For ease of conversion of instrumental magnitudes to the U-B-V system, Walker and Hardie will extend the list of U-B-V standards evenly around the sky in two zones, one at declination $+45°$ and the other at either declination $0°$ or $-10°$. The $45°$ zone will contain six regions separated by 4 hours of R.A. The $0°$ zone will contain eight regions separated by 3 hours of the R.A. Each region will contain four stars; one red and one blue star of 8th magnitude, and one red and one blue star of 10th magnitude. These stars will serve as zero-point stars and as stars to determine the transformation equations from the observer's natural photo-electric system to the U-B-V system.

(*d*) For rich clusters where complete photo-electric coverage is impractical, photographic plates will be used for interpolation between the photo-electric standards. Modern iris photometers must be used for the measurements of the plates.

The Hamburg Observatory has offered to co-operate with any group interested in this cluster program. They will furnish photographic plates in three colors taken with their Schmidt telescope, if any other group will furnish photo-electric standards.

(D) TRUMPLER'S CATALOG

Weaver reported that Trumpler was preparing his extensive cluster data for publication at the time of his death. The material consists of (*a*) a catalog which lists the *X* and *Y* co-ordinates, the radial velocity, the spectral type on Trumpler's own system (which is close to the Yerkes MK-system) and estimates of colors and magnitudes for nearly 5000 stars in 100 clusters; and (*b*) identification charts for each cluster with the *X* and *Y* co-ordinates superposed and each star of the catalog marked. At the time of his death, Trumpler was attempting a conversion of his photometry to the B, V system. This was only partially completed. Weaver stated that the identification charts and the radial velocities were, however, completed and were nearly ready for the printer. The conference urged Weaver to continue with the preparation of Trumpler's material for the press. Both Weaver and the conference delegates stated that Trumpler's color and magnitude estimates should be published to guide future photometric observers, but that no large effort should be made to put these values on the B, V system because present-day requirements will necessitate photometric re-observation in any case. Time is the important point with regard to Trumpler's data. The material will be of such great value in guiding the precision photometric job on many clusters that it should be published as soon as possible. Weaver estimated that the entire material would be in the hands of the printer by the fall of 1958.

(E) DISCOVERY OF NEW CLUSTERS

The discovery and study of very distant clusters is important for the calibration of the galactic distance scale adopted in the interpretation of radio observations. But complete discovery of the nearby loose clusters is also important for studies of the age distribution of clusters because this may give information on star formation rates as a function of time. Two separate discovery techniques are available. These are: (*a*) inspection of direct photographs to identify clumpings of stars; (*b*) inspection of objective-prism plates taken with Schmidt cameras to identify a spectral type-apparent magnitude relation.

Haffner's experience with method (*a*) shows that loose, large diameter aggregates are easier to discover with instruments of small focal length and small aperture than with large Schmidt cameras. For example, Haffner reported discovery of twenty possible new clusters in Canis Major and Puppis with a 120-cm focal length telescope in South Africa. These

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groupings can be located only with difficulty on the Palomar Sky Atlas. The many faint background stars decrease the contrast between the cluster and the field and the cluster is lost on plates reaching to faint magnitudes.

Nassau reported on Stock's work on the location of new clusters by the objective-prism technique. Stock used a 4° prism on the Cleveland Schmidt and found twenty-one suspected clusters by this method, each of which showed a similarity of spectral type at a given apparent magnitude. The suspected clusters were found from survey plates taken along the galactic plane in a band $\pm 6°$ wide in latitude and extending from longitude 200° through 0° to 340°. The limit of the survey was about 10·2 photographic magnitude. Three natural groups emerged from Stock's data. These were B clusters, B-A clusters, and F clusters where the F stars were probably giants.

The Cleveland group plans to extend the program to fainter magnitudes to check for the required H-R diagram which must be present for a real cluster. The new survey will again extend from $l = 200°$ through 0° to 340° in a belt $\pm 6°$ wide, and will reach 13·2 photographic magnitude with the 2° prism. The plate material will be so extensive that Nassau proposes to make copies of the plates available to interested observatories at the cost of reproduction. Tests of the quality of reproduction made by the Eastman Kodak Company showed that spectral classification was as precise on copies as on the original plates themselves. The discovery plan would then be to search these plates for spectral groupings with the expected apparent magnitude range necessary for a real cluster. In this way a large number of clusters which are too loose to be easily picked up from direct plates would be discovered. Nassau estimated that about 370 plates would cover the galactic belt available from Cleveland. The estimated cost of reproduction of 370 plates is about $300.

Lindblad mentioned that the Stockholm Observatory has started a similar discovery survey for southern clusters using the ADH Schmidt of the Boyden Station. There will be some overlap with the Cleveland survey so that a systematic comparison can be made of completeness factors. The dispersion of the Stockholm survey will be nearly the same as that used by the Cleveland group.

Haro stated that the Tonantzintla objective-prism survey covers a belt 10° wide centered on the galactic plane extending from the Coal Sack in the south to Cassiopeia in the north to a limiting magnitude of 13. Copies of these plates can be made available on the same basis as the Cleveland survey at cost to any observatory wishing systematically to work up the material.

Weaver mentioned that the certainty that a given spectral grouping was really a physical cluster was difficult, especially when the grouping is loose and submerged in a dense background field. Nassau agreed and stated that the grouping merely provided a finding list from which objects could be chosen for extensive study. All agreed that to prove existence of a physical grouping requires proper motion study, accurate photometry, and some radial velocity work. Weaver emphasized the importance of the spectral survey method of discovery because here, for the first time, was a way to pick up a class of clusters which have relatively few stars, which often begins at a late spectral class (A or F), and which may be the most numerous class of clusters in the sky but which we know next to nothing about. A nearby example of such a cluster is Coma Berenices which Trumpler showed [2] to have less than fifty stars brighter than visual absolute magnitude +6. Such a cluster would be undiscovered by inspection of direct plates if it were at a greater distance because it would merge into the background field.

Heckmann illustrated not only the fruitfulness of detailed study of such loose aggregates but also the enormous work involved in proving physical existence and membership by describing proper-motion and photometric work at Hamburg on the α Persei aggregate. For many years this cluster was known only as an aggregate of B and early A stars centered on α Per. No later type stars were believed to be present in the group. But a recent proper-motion study [3] in a field 5° square centered on α Per has now shown that the main sequence exists in this cluster extending at least as faint as G stars. It is impossible to pick out these faint members even statistically on direct plates because of the small ratio of cluster to field stars. Only by combination of proper-motion and spectral techniques can the true cluster population be found. Heckmann and Morgan emphasized the need for many studies of this kind to properly calibrate the absolute magnitudes of the B stars in loose aggregates. The need is to first get a finding list of possible loose clusters by the discovery technique employed by Stock and described by Nassau, Vyssotsky, and Lindblad, and then follow up with proper-motions, photometry, and spectral classification.

Although proper-motion data are essential to separate cluster members from field stars, it is often useful to make a statistical estimate of the number of superposed field stars to be expected in a color-magnitude diagram. This requires knowledge of the distribution function A (m, CI) where A is the number of stars per unit area at m in dm with colors CI in dCI. Parenago reported work by one of his collaborators, Mrs Starikova, on the

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computation of A (m, CI) from a generalized Schwarzschild equation

$$A\ (m, \mathrm{CI}) = \omega \int_0^\infty D\ (r)\ \phi\ (M, \mathrm{CI})\ r^2 dr.$$

Parenago stated that comparison of the observed and computed A (m, CI) for any field provides a test for the presence of a true cluster.

(F) THE H-R DIAGRAM AND STELLAR EVOLUTION

(1) *The nearby stars*

Parenago discussed the H-R diagram for the nearby stars using spectral types and U-B-V colors for 851 stars with trigonometric parallaxes greater than 0."03. Separation of the luminosity classes VI, V, IV and III was made on the diagram. Where estimates were not available, Parenago established the luminosity class from plots of spectral type against U-B. The separation was remarkably clear in these plots and showed that a powerful discriminate of absolute magnitude of a given spectral type is the U-B color. The classes VI (sub-dwarfs), V (main sequence), IV (sub-giants), and III (giants) appear to be separated on discrete sequences in the H-R diagram and Parenago interpreted these sequences as the result of stellar evolution by corpuscular radiation with consequent mass loss—a view which differs from the ideas of Schwarzschild and his school. Parenago pointed out that some of the sequences in the H-R diagram are running parallel to lines of constant radii and some are nearly perpendicular to these lines. He concluded that after an initial contraction from the interstellar medium a star can have two different types of development, one in which there is only a moderate change of radius as it evolves, and another in which a large change of radius is involved. No discussion was made of how these ideas apply to the systematic data available for star clusters, The final point which Parenago discussed was the identification of the main sequence in the globular clusters with the subdwarfs and high velocity giants of the nearby stars. With this identification, a fit of the C-M diagram of M 3 with the sub-dwarfs gives an absolute magnitude of +1·5 for the RR Lyrae stars in M 3. The identification of certain field stars such as Arcturus and γ Leonis with the globular cluster sequence was also suggested.

(2) *Binary stars*

Binary systems provide unique information about certain aspects of cosmogony and stellar evolution. Members of a binary system are undoubtedly of the same age but often differ in mass, absolute magnitude,

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and spectral type. This feature permits the study of evolutionary patterns in various stages of a star's complete history. Kulikovsky presented a summary of a study of 173 wide pairs. Spectral types, apparent magnitudes, and magnitude differences were used and the H-R diagrams for these pairs was obtained, but only with some difficulty because of the lack of data for many systems. Kulikovsky urged that interested observers should obtain photometric, spectroscopic and parallax data on many binary systems so that a complete study could be made. Many systems are easily accessible to observation but, strangely enough, are almost completely lacking in data. One typical example is π Andr with components of the 4th and 8th magnitude separated by 36 sec of arc. The spectral type and colors are unknown for the companion. According to Kulikovsky twenty such easy cases exist within reach of only moderate instruments. Following a recommendation of Commission 26 of the I.A.U., Kulikovsky suggested that observers with large instruments should undertake spectral classification, photometry, and parallax determinations for a list of binary stars selected to be of the greatest interest. Kulikovsky is willing to prepare such a list and will communicate this to any interested observer. Parallax observations are especially desired and the parallax observers at the Yerkes, Dearborn, Swarthmore, and Leander-McCormick observatories should be alerted.

Bidelman at Lick has a large spectral classification program under way for the components of binary stars and Oke and Bakos at the David Dunlap Observatory have undertaken photo-electric photometry on wide pairs to obtain a C-M diagram. Both these efforts are along the lines suggested by Kulikovsky. Co-ordination of effort may be desirable. If so, it can best be accomplished by private correspondence between the interested parties.

(G) ASSOCIATIONS

Kharadze stated that no observatory has a regular program for the study of spectral characteristics of stars located in regions of large diffuse hydrogen nebulae. These stars have been discovered and investigated by A. H. Shajn in associations and star chains. At Abastumani Observatory spectral classification and spectro-photometry has begun for these stars with a new meniscus telescope of 70 cm aperture with an objective prism of the same size.

Flare and flash stars are common in T associations. But the question of their general space distribution is not settled. There are at least two schools of thought. Kholopov believes that flare and flash stars are distributed uniformly over the sky, while Haro's experience suggests that they are concentrated in T associations. Haro also suspects that there is a correlation of the characteristic flare time with the type of association in which the stars are located. For example, in the Orion association the flare time from minimum through maximum and back to minimum is about 120 minutes according to the Tonantzintla observations. In the S Mon association (NGC 2264) the characteristic time is about 60 minutes according to Haro's data and about 40 minutes according to Rosino. In the Taurus dark clouds, the time is only 28 minutes. This is obviously a new and important field in which much work remains to be done. The problem is important from the standpoint of the initial origin of stars because M. F. Walker's observations of C-M diagrams of young associations show that T Tauri stars (and some flare stars?) are probably in the stage of gravitational contraction to the main sequence and may represent the earliest stage in the life of a star which can be directly observed. Haro emphasized the need for detailed work on this problem and stated that co-ordination could be made through the committee on problems of T Tauri stars composed of Herbig, Haro, and Kholopov, which was appointed at the Burakan conference in 1956. All interested observers with suitable equipment should contact this committee concerning co-ordination problems.

References

[1] See, for instance, Sandage, A. *Atroph. J.* **125**, 435, 1957.
[2] Trumpler, R. J. *Lick Obs. Bull.* **18**, 167, 1938.
[3] Heckmann, O. and Lübeck, K. *Mitteil. Astr. Ges. 1956*, **16**, 1957; see also *Z. f. Aph.* **45**, 243, 1958.