Chapter VI

Review Papers

Summary

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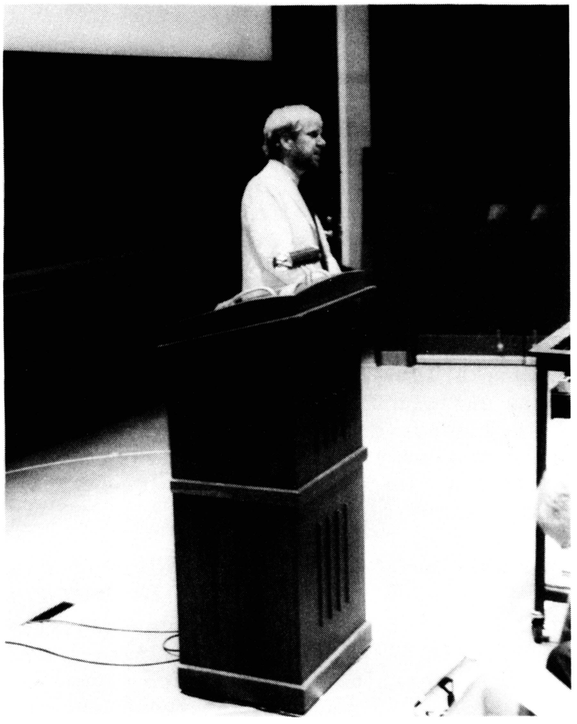
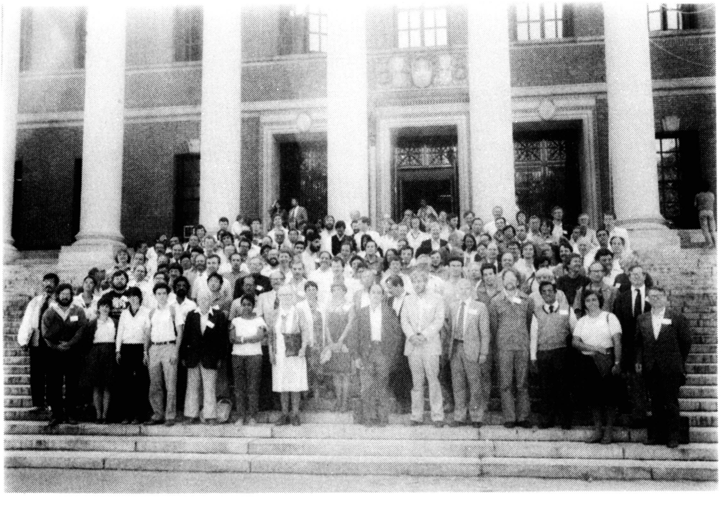


Josh Grindlay thanks attendees for not being in China



Another view of the Symposium participants

GLOBULAR CLUSTER SYSTEMS IN GALAXIES: MAIN TRENDS AND FUTURE DIRECTIONS

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This was a really exciting conference! The main problem in summarizing it is that so many new and important results were presented, making it impossible to mention each one individually. In reviewing this conference I shall first discuss new results, then problem areas revealed by papers and during discussions and finally desiderata and trends for future work.

1. NEW RESULTS:

Perhaps the most impressive feature of this conference has been the tremendous increase in the observational database on Galactic and extra-Galactic globular clusters. Mainly due to the advent of CCD detectors numerous new precision color-magnitude diagrams (Peterson 1986) have recently become available. Hesser, Shawl and Meyer (1986) have provided a uniform database on the radial velocities of globular clusters and Peterson and Reed (1987) and Djorgovski (1987a) have provided much new information on the structural parameters of globulars. Finally Harris (1987) has given us an excellent review of recent progress on the study of globular clusters in extra-Galactic systems.

2. At a number of other meetings on globular clusters (e.g. IAU Colloquium No. 68) and Population II during the last few years the abundance scale for globular clusters had been a subject of lively controversy. This problem now appears to have been settled to almost everyone's satisfaction. The source of problems with the [Fe/H] scale derived from echelle spectra seems to have been traced to difficulties with the placement of the stellar continuum.

3. One of the most exciting results presented at this conference consisted of the discovery by McClure et al. (1987) that the slopes of the luminosity functions of globular clusters correlate with their metallicity in the sense that metal-poor clusters have steeper mass spectra than do metal-rich ones. If this correlation is confirmed by subsequent observation it might provide valuable new insights into the

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mechanisms by which globular clusters form and subsequently fragment into stars. A slight extrapolation of the observations to higher masses and luminosity suggests that flat spectrum (high metallicity) clusters will contain a larger number of neutron stars than metal-poor clusters, as discussed by Grindlay (1987).

4. Don VandenBerg (1987) showed us that models for metal-poor stars, that are enriched in oxygen, appear to give a slightly better fit to the observations than do models in which the mix of heavy elements is essentially solar. This result is, perhaps, not unexpected since supernovae, such as Cassiopeia A, (which had a very massive progenitor), are observed to eject large quantities of oxygen. With this enhanced oxygen abundance globular cluster ages are reduced to 13 to 14 Gyr. Finally VandenBerg showed that presently available color-magnitude diagrams for globular clusters are consistent with the hypothesis that any age differences between Galactic globular clusters are < 1.5 Gyr. It would, however, clearly be very worthwhile (and difficult!) to extend main sequence photometry to globular clusters situated very close to the Galactic center and to clusters in the outer Galactic halo to see whether cluster formation took place synchronously over the entire proto-Galaxy. A number of Symposium speakers emphasized the fact that populous clusters in the LMC and SMC exhibit a wide age range in contradistinction to the Galactic globulars which all appear to be approximately coeval.

5. Harris (1987) showed that the Coma galaxy NGC 4874 has a high specific globular cluster frequency. This observation strengthens the conjecture, previously based on observations of only 3 galaxy clusters, that the central galaxies in rich clusters are special. In fact such central galaxies must be special _ab initio_ if the globular clusters in such systems are older than their parent galaxies. Considerable support for this idea was provided by new observations by Judy Cohen (1987) which support similar results obtained previously by Forte, Strom and Strom (1981).

6. We now understand that spheroidal galaxies (Wirth and Gallagher 1984, Kormendy 1985) have structural parameters which show that they differ from ellipticals. At this meeting Gary Da Costa (1987) showed us that the stellar content of dwarf spheroidal galaxies differs substantially from that encountered in Galactic globular clusters. It is important to remember that the spheroidal galaxy "form family" comprises both relatively luminous objects like NGC 147, NGC 185 and NGC 205 and low luminosity dwarf objects such as And I, And II, And III near M31 and the "seven dwarfs" associated with our own galaxy.

7. The radial density distribution of globular clusters appears to be intermediate between that of elliptical galaxies, for which $\rho \propto r^{-3}$, and that of dark matter which has $\rho \propto R^{-2}$. In particular the observations by Mould et al. (1986) and Huchra (1987) demonstrate that the globular clusters associated with M87 exhibit kinematical properties which show that the mass distribution derived from globular

clusters smoothly joins that derived from integrated starlight (Sargent et al. 1978) and that calculated from X-ray emission of hot gas by Fabricant and Gorenstein (1983).

8. Tremendous progress (Inagaki 1987, Cohn 1987) has recently been made in our understanding of the pre- and post core collapse phases of cluster evolution. These studies show that clusters will expand on a timescale comparable to the Hubble time after core collapse i.e. there is life after core collapse! The importance of these theoretical studies is enhanced by recent observations of cusps in clusters cores by Djorgovski and King (1986). John Bahcall (1987) provided some stunning simulations of Space Telescope data which show how much information ST may be expected to provide on the crowded central regions of globular clusters. In the meantime studies of the same problem are proceeding at somewhat lower resolution with the Canada-France-Hawaii Telescope.

9. Innanen (1987) pointed out that Population II stars with low angular momentum orbits will be scattered into "chaotic orbits" by the mass concentration near the nucleus of our galaxy. As a result there should be a marked deficiency of such stars in the vicinity of the Sun. From inspection of orbital data in the Gliese and Woolley Catalogs Innanen very tentatively concludes that the circular velocity near the Sun is 235 ± 10 km s^{-1}. It is particularly interesting to note that this value does not depend on any assumption regarding R_o. It would be very interesting to strengthen these results by looking at the velocity components of the Lowell proper motion stars.

10. In his review Renzini (1987) pointed out that observations of globular clusters may already rule out the existence of weakly interacting massive particles (WIMPs) via the effect that these objects have on the computed lifetimes of globular cluster horizontal branch stars. With semi-convection, $\tau_{AGB}/\tau_{HB} = 0.14$ compared to $\tau_{ASB}/\tau_{HB} >$ 1.5 for WIMP models. The observed value $\tau_{AGB}/\tau_{HB} = 0.15$ seems to rule out the presence of WIMPs.

PROBLEMS:

1. More than twenty years ago (van den Bergh 1965) I stumbled on the "second parameter" problem. At that time I suggested that this second parameter might be due to either age differences between clusters or to different relative abundances of elements heavier than hydrogen. During the last two decades much new observational evidence has been found for the existence of a second parameter but our understanding of its nature has not really improved. In fact the problem may have become somewhat worse. In his review, Jim Hesser (1987) showed us that modern high-quality color-magnitude diagrams of such clusters as M13, M92 and NGC 5466 show subtle but distinct differences among blue horizontal branch clusters suggesting that more than one parameter, in addition to metallicity, may be required to describe cluster color-magnitude diagrams.

2. Our understanding of the Oosterhoff (1939) classes (van Albada and Baker 1972) has not really improved in recent years nor has our knowledge of the metallicity dependence of the absolute magnitudes of RR Lyrae stars (Sandage 1981). At the present meeting papers like those of Cacciari, Clementini and Prevot (1987) and Jones et al. (1987) show no evidence for the expected metallicity dependence of the absolute magnitudes of RR Lyrae stars. Recent observations by Pritchet and van den Bergh (1987) show that the halo of M31 appears to resemble an Oosterhoff Type I population. For 24 RR Lyrae stars $\langle P_{ab} \rangle = 0.548$ while the variables with largest amplitudes have $0.45 < P < 0.50$ days.

3. One of the most hotly debated issues at this meeting was the question as to whether globular clusters represent fair samples of halo populations. From the similarity of the kinematics of Galactic high velocity stars and globular clusters the answer to this question appears to be "yes". On the other hand Harris (1987) emphasized that there are important differences between globular clusters and associated halo populations in external galaxies:
(a) In elliptical galaxies the distribution of globular clusters is more extended than that of the background galaxy light.
(b) Isopleths of globular clusters are found to be rounder than the galactic isophotes.
(c) Globular clusters are bluer (and hence presumably metal-poorer) (Cohen 1987, Forte, Strom and Strom 1981) than the galaxy background on which they are superimposed.
(d) Globular cluster systems appear to be dynamically hotter (Mould, Oke and Nemec 1986, Huchra 1987, Lauer and Kormendy 1986 and Grillmair, Pritchet and van den Bergh 1986) than their parent galaxies.

Ostriker (1987) cautioned that the presently observed distribution of globular clusters might have been affected by tidal friction, disk shocks, etc. The observation by Grillmair et al. (1986) that there is no noticeable radial gradient in the luminosity function of the M87 globular clusters does, however, place constraints on the importance of dynamical friction as a contributor to the difference in the core size of M87 and its globular cluster system. Detailed numerical simulations by Muzzio (1987) have shown that swapping of globular clusters may be an important factor for cluster galaxies. His computations do, however, show that stripping of normal cluster galaxies cannot account for the huge excess cluster populations associated with central galaxies of rich clusters.

4. Pritchet and van den Bergh (1987) have studied a 2 x 3 arcmin field situated along the minor axis of M31 at a distance of 40 arcmin (9 kpc) from the nucleus. In this field they detected 32 variables of which 30 are either confirmed or probable RR Lyrae stars. From the frequency of multiple discoveries of individual variables these authors estimate that their data are only ~25% complete. The total number of RR Lyrae stars in their field is therefore probably of the order of 120. For comparison it is noted that this M31 field would contain only ~2 variables if its stellar population were similar to that of the

cluster 47 Tucanae and ~200 variables if it were like M3. From the study of the red giant stars in a field adjacent to that of Pritchet and van den Bergh, Mould and Kristian (1986) estimate a mean field star metallicity <[Fe/H]> ~ -0.6 i.e. a value similar to that of 47 Tucanae for which Gratton, Quarta and Ortolani (1987) find [Fe/H] = -0.8. The most likely explanation for the observation that the M31 halo is both variable-rich and relatively metal-rich is that the halo of the Andromeda nebula contains a population of old metal-rich stars with a strongly developed horizontal branch. In this respect the halo of the Andromeda nebula would then resemble the M31 globular clusters which exhibit strong metallic lines and strong Hδ simultaneously (Burstein et al. 1984). Confirmation of the hypothesis that M31 globular clusters have unexpectedly strong blue horizontal branches is provided by the IUE observations of the cluster Bo 158 (Cacciari et al. 1982). The most straightforward interpretation of these observations is that the M31 globular clusters and the halo stars in the Andromeda nebula exhibit similar "family traits" which differ systematically from those of halo stars and globular clusters in the Galaxy. A special search for RR Lyrae stars in metal-rich Galactic globular clusters (Hazen 1987) shows a low specific frequency of RR Lyrae stars in the clusters NGC 6388 and NGC 6652. A specific frequency of cluster type variables, which is only a factor a 3 or 4 lower than that in the M31 halo field studied by Pritchet and van den Bergh (1987), is found in NGC 6569. It would be interesting to see whether the relatively high RR Lyrae star frequency in the latter cluster is unusual or whether Zinn and West's (1984) metallicity estimate [Fe/H] = -0.86 might be too high.

5. Recently Lacey and Ostriker (1985) have suggested that the missing mass in galactic halos might be in the form of $\sim 10^6$ $M_\odot$ black holes. Wielen (1987) examined the effects which the presence of $\sim 10^5$ such "Nemeses" would have on Galactic globular clusters. His calculations showed that a large population of black holes might devastate parts of the Galactic globular cluster system. More detailed computations will be required to see which constraints the observed distribution and luminosity function of Galactic globular clusters places on such hypothetical massive black holes in the Galactic halo.

FUTURE:

1. All indications are that high-resolution ground-based observations, and eventually observations from Space Telescope, will contribute tremendously to our understanding of density cusps and collapsed cores in globular clusters (Bahcall 1987). Such observations should also provide information on gradients of blue stars (Nemec and Harris 1987), the hypothesized dwarf enrichment in some cluster cores (Rose and Tripicco 1986, 1987), X-ray sources etc.

The discovery of highly obscured globular clusters (mainly near the Galactic center) would be important so that we can study a complete sample of Galactic globular clusters. Djorgovski's (1987b) use of the IRAS database to search for obscured clusters near the Galactic center is a good first step in this direction.

3. It was somewhat disappointing to me that so little attention was paid to the flattening of globular clusters at this meeting. We now know from kinematical studies of a number of globular clusters that this flattening is due to rotation. Flattening of clusters therefore provides information on the angular momentum of globular clusters. A major mystery is why galactic open clusters and globular clusters are almost spherical whereas the young and old clusters in the Magellanic Clouds are much more flattened (van den Bergh 1984). Good first steps in the study of cluster ellipticities are provided by White and Shawl (1987), by Djorgovski (1987a) and by Spassova, Staneva and Golev (1987) who have studied the flattenings of clusters in M31.

4. The new observations reported by Harris (1987) greatly strengthen the hypothesis that the central galaxies in rich clusters are unusual *ab initio*. Since cD galaxies are central galaxies *par excellence* it would be very interesting to study the frequency and distribution of globular clusters in cD galaxies. The nearest example of a cD galaxy in a rich cluster is NGC 6166 with V_0 = 9075 km s^{-1}. If this object is similar to M87 one would expect it to contain ~140 globular clusters brighter than B = 25 and ~900 globulars with B < 26. These objects would appear to be within range of CFHT and could be studied in great detail with the Hubble Space Telescope.

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