# CONFERENCE SUMMARY

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## 1. What are Stellar Populations?

Of all the subfields which make up the discipline of astronomy today stellar populations must surely be one of the most difficult to explain to the lay person. From the first day of this meeting I took the notion that this was the invention of a charismatic individual with a particular genius for bridging the gap between stellar and extragalactic research, a bridge which is probably still very relevant to maintain today.

Stellar populations is not the study of stars *per se*, nor is it the study of galaxies *per se*. Rather, it is the study of those characteristics of stars and galaxies that tells you how galaxies formed and evolved. We study the ages, kinematics, and chemical composition of stars with a view to learning from these conserved quantities how galaxies were put together from their component parts. Redefinitions of the subject were offered more than once in the meeting, and I'll return to this later.

One might well ask how a subject which is 50 years old can still be a vital and fascinating one. The answer, I think, is to be found in the far-reaching objectives of the subject, to understand galaxy formation. In that sense we can truly say that stellar populations is in the state in which Owen Gingerich told us a reviewer of stellar evolution found himself in the 1930s, namely a state of real ignorance, a state in which the important answers still lie ahead of us.

An economic rationalist might ask us: why are you spending all your time collecting all this irrelevant data about different kinds of stars in the Galaxy? Isn't stellar populations just a convenient sack into which you astronomers throw every kind of redundant data collecting that you enjoy



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doing? If understanding galaxy formation and evolution is your goal, why don't you focus on it and use look-back time observations to address your questions directly?

I think the correct answer to this question is to point to the effects of what an Australian historian calls the tyranny of distance in astronomy. We see so little in detail far away that we are forced to pay special attention to everything that is close to us. Nonetheless, as is often the case in our confrontations with the economic rationalists, it doesn't hurt to pay some attention. Indeed, a meeting like this is an opportunity to refocus on our goals.

## 2. Stellar Populations in the Galaxy

The paradigm for galaxy formation in the 1990s is clearly assembly, accretion, merger and infall, rather than rapid collapse from the 100 kpc protogalaxy envisaged thirty years ago. This shift has come about as a recent of a number of developments. One is the success of numerical models of the growth of structure in the Universe. This was emphasized by Gilmore and Wyse. A second is the non-detection of the initial burst of star formation in protogalaxies. Another is the growing evidence for inhomogeneity in the halo of the Galaxy, although its interpretation as an age spread remains observationally contestable. But the 'smoking gun' evidence for this picture presented at this meeting was the discovery of the Sgr dwarf spheroidal galaxy. And the candlestick-in-the-library, if we are to persist with this metaphor, is the presence of high velocity $10^8$ year old main sequence stars in the Galaxy, although there is a tricky unanswered question here regarding phase-mixing of the young stars, which may provide an alibi in this case.

If this is how the halo was assembled, it is also very instructive to see what it is that the halo was made from. The beautiful 'third generation' colour-magnitude diagram of the Carina dwarf by Smecker-Hane *et al.* showed in a most striking way a dwarf with an old horizontal branch and an intermediate age core helium burning clump, together with appropriate and confirming distributions of main sequence stars. It is tempting to close the loop on the protogalaxy problem by identifying these objects in their earlier guise (dwarf irregulars) as the faint blue galaxies seen in abundance at intermediate redshifts. The recent Keck HIRES observations of the line widths of faint blue galaxies support that identification. To put it another way, the rapid collapse theory predicted luminous protogalaxies at high z: these have not been observed. What we began by calling the Searle-Zinn theory (now subsumed by generic growth-of-structure simulations) requires instead a rash of blue dwarfs at modest redshifts: these we do see and, indeed, need to fit into the general scheme of things. We need to develop these ideas in quantitative terms in the context of luminosity functions and space densities, in order to have a model which can be tested.

If this is how the luminous halo formed, how did the disk form? Gilmore suggests to us that the thin disk formed from the thick disk. But this assumes that we have excluded the other hypotheses he offered for the origin and role of the thick disk: origin as a spheroid, heating, accretion, and diffusion. The first of these hypotheses does seem to be ruled out by the consensus of a number of studies reporting the rotation of the thick disk, for example Norris' work and the work of the Besancon group. Further study of the age distribution and kinematics of the thick disk would seem to be required to properly exclude these other hypotheses. Much of this work is in progress according to poster presentations which are part of this meeting, and it is rather desirable that this new work focus on the hypotheses to be tested. At the same time we should keep in mind that our model for galaxy formation is a messy one with long timescales and some discrete events. It is not surprising that the data on transitional populations is confusing. We should be careful not to force an inappropriate model on the data.

Physical models of disk formation are now appearing for the first time. White outlined the sequence of events in his models and those of Ostriker:

- initial clustering in the dark matter component,
- dissipation in the gas component,
- feedback via star formation.

Successful treatment of the physics of this third stage is evidently a prerequisite for successful comparison with observations.

## 3. The Neighbourhood

To understand the formation of galaxies in this way we must study the building blocks nearby. The glimpses we have seen of the potential of WF-PC2 to teach us about the building blocks are among the most exciting new results of the meeting. The general characteristics of these dwarf galaxies are as follows:

- a dark halo
- an underlying old or intermediate age population
- multiple epochs of star formation
- a tendency to be gas rich

The ongoing work on M/L in dwarf spheroidal galaxies was reported by Pryor *et al.* The ubiquity of old populations was asserted by Saha, although subtleties may be present in the age of the initial burst, and will presumably be clearly revealed, for example by HST studying the oldest Magellanic clusters. Investigation of the star formation history of these dwarfs is becoming less subjective thanks to ongoing work in Bologna and Baltimore. We also heard (and the circumstantial evidence has been noted before) that as dwarf galaxies approach the host galaxy halo, their gas tends to be lost, and star formation is quenched. A number of physical mechanisms could be proposed, evaporation, ejection by stimulated star formation, ram pressure stripping. Detailed studies of these processes would be an interesting extension of the pioneering work of Quinn *et al.* Production and confinement of the Magellanic Stream may be a useful guide for this work. And on the observational side, we sorely need a systematic survey for dwarf spheroidal galaxies, so that we can speak quantitatively of space densities and accretion rates.

## 4. Clusters are Clusters

Have we finally put semantic debates about star clusters behind us? We heard a more physical approach from the all three speakers on star clusters. The working hypothesis seems to be:

- clusters all form from giant molecular clouds; they may be a multi-parameter family, but they are all one species;
- the different luminosity functions of cluster systems may be an acquired trait, rather than a genetic one;
- there may be a universal initial metallicity distribution function (MDF) for cluster systems.

This last point needs development. This is a hypothesis with the virtue of simplicity. Its implications might be far reaching. Examination of Local Group galaxies provides some support for the notion that 'true' Population II clusters might be drawn from a common distribution. (There is already the hint of some data filtering here.) The idea of such a universal function has to deal with two objections and three tests:

- Can there be such a thing as an initial MDF, other than that provided by primordial nucleosynthesis, unless there is some phase of pregalactic cluster formation?
- There is a correlation of mean metallicity with the mass of the host galaxy; the metal rich MDF seen in the inner parts of giant ellipticals would need to be ascribed to second generation cluster systems.
- Are the age distribution functions of cluster systems identical?
- Is the blue tail of the MDF due to young clusters or extremely metal poor clusters?
- Assuming the latter is true, can we approach arbitrarily close to primordial composition, given the very large samples of clusters now available for study?

Hesser warned us of the dangerous fauna and flora of the globular cluster second parameter jungle. Indeed, there is a poster from Sao Paolo on third parameter phenomena. We heard quite explicitly at this meeting that the hard evidence for age being the second parameter in the globular cluster family is not yet in the bag. From the previews we saw of distant globular cluster colour-magnitude diagrams with WFPC2, there is surely a good case for a comprehensive study of the outer halo clusters with HST. And on the subject of absolute ages of clusters, more than one speaker remarked on the opportunity to measure the abundances of those elements that determine the stellar structure of globular cluster main sequence stars with HIRES on the Keck telescope. It is worth recalling that the last doubling of optical telescope aperture gave us the first estimate of globular cluster ages from the pioneering photoelectric photometry of turnoff stars by Sandage. The latest doubling can finish the job by obtaining the high resolution spectra of these same stars.

## 5. Ellipticals

Classically, elliptical galaxies appear the most simple in structure and the most simple in parameter space. We have been fond of calling them a one parameter family. This seems to contradict the emerging view that ellipticals have the most complex star formation history. The contradiction resolves itself when we remember that the timescale for a young population to fade is $10^9$ years. If age (or time-of-last-merger) is an important parameter in ellipticals, it is possible to hide its effects fairly fast. The parameter describing ellipticals which does not fade is metallicity, and colours and line-strengths remain very sensitive to that parameter over their full lifetime.

Let us review the subtle age indicators in ellipticals. These observables are sensitive to both time-of-last-merger and mean age, the former probably being more influential:

- Balmer lines
- mass-to-light-ratio
- mean and fluctuation colours
- planetary nebula frequency
- alpha/iron ratio
- fine structure parameter

We are fortunate to have an array of indicators with which to tackle this difficult problem of learning about the content of elliptical galaxies, now that the premise that ellipticals are a globular cluster population is untenable. We are more fortunate to have an emerging set of diagnostic models with which to interpret these data. Just as cluster colour-magnitude diagrams provide an opportunity to tune up stellar evolutionary models, so we need to apply the same iterative approach to stellar population models, to be sure we end up with the right conclusions. Some illustrative considerations:

The direct age dependence of H$\beta$ arises from the main sequence turnoff temperature. But H$\beta$ is equally influenced by the horizontal branch, and also affected by Balmer emission, cyanogen strength, and metallicity.

The mass-to-light-ratio of a stellar population depends on the presence of stellar remnants and low mass stars. This is another way of saying that it depends on the initial mass function. M/L also varies with metallicity as discussed by Renzini. Depending on the importance of these effects, the observed spread in M/L would be consistent with as little as a fading time or as much as a Hubble time.

Far-UV spectra are sensitive to the complex late stages of stellar evolution; we are learning as much about evolution from these spectra at the present time as we are learning about the stellar systems themselves.

I believe we should be thoroughly optimistic about our progress with the integrated light problem at the present time. We should not be daunted by the fact that there is an n-dimensional parameter space to explore, because there are a large number of directly relevant observational constraints and a great deal of experience within the population synthesis subfield of the complex task of model fitting. The parameters used to be very largely *ad hoc* ; now they are becoming physical. Renzini proposed three tests of population synthesis models:

- tight relations between colour and line strength versus mass (velocity dispersion),
- a tight fundamental plane (M/L versus mass),
- repeat the above at redshifts which are significant evolutionarily.

We can also expect the observational situation to improve, for example with a better UV camera for HST. And Miras in Virgo ellipticals should be detectable in the infrared. The appropriate HST camera for that purpose is in the pipeline.

## 6. What is a Stellar Population?

It seems no two people agree on a definition of a stellar population, but everyone uses the term. With his assertion that "anyway, stars are people", Fusi-Pecci appeared to redefine the subject as astrosociology. From Schweitzer's declaration that the Hubble sequence is to do with the "number, type, and vehemence of mergers", one might take it that pure population I means young or undisturbed, while pure population II means old or experienced. Olszewski reminded us of Hodge's population boxes and redefined populations as "the major events in the life of a galaxy". King would prefer us to dispose of the terms Population I and II and a number of other misnomers.

Likely as not, we shall understand galaxy formation before we agree on this definition.