STELLAR EVOLUTION AND THE POPULATION CONCEPT AFTER 1950; THE VATICAN CONFERENCE

A. BLAAUW
Kapteyn Astronomical Institute,
P.O. Box 800, 9700 AV Groningen, the Netherlands
(secr@astro.rug.nl)

1. Introduction

In the development of the concept of stellar populations the classification scheme adopted at the Vatican Conference of 1957 represents a major milestone. Thirteen years after Walter Baade's seminal papers, the conference reviewed progress in relevant fields of research and formulated a classification of population types that would remain the principal reference for the next decades. I shall review developments preceding the Conference, the initiatives that led to the Conference, the new scheme, and a few developments of later date.

Baade's scheme of 1944 was of an extreme simplicity and had an almost exclusively photometric-observational base. It defined the two population types by means of two physical parameters, absolute magnitude and spectral type, to which Baade added one kinematical reference, the so-called high-velocity stars of the solar neighbourhood. No reference to stellar evolution entered his definition. In his introductory paper at the Vatican Conference he said:
"When I succeeded in 1943 in resolving the central region of the Andromeda nebula and its two companions NGC 205 and NGC 221, it became clear that in dealing with galaxies we have to distinguish two different kinds of stellar populations, which I called population I and II. Of these two the population I presented nothing new. It is the population of the spiral arms of galaxies and we are well acquainted with it because our sun is located in a spiral arm of our galaxy. - - - Prototype of the population II are the stars in globular clusters. Their color-magnitude diagram, entirely different from that of population I, has been known for more than a quarter of a cen-

P. C. van der Kruit and G. Gilmore (eds.), Stellar Populations, 39–48.

tury and again represented nothing new. But new was the realization that the globular clusters are the representatives of a second widespread stellar population which had remained unrecognized [in other galaxies] because its brighter members are a hundred times fainter than the brightest stars of population type I."

and:

"Two points I like to stress here. Since the two populations are defined by their color-magnitude diagram, [...] the populations are defined in a physical sense. The second is that in dividing the stellar populations into two main groups we use the same dividing line by which we assign the star clusters [in the galaxy] to either the galactic or the globular group, depending on the topology of their color-magnitude diagram."

The simplicity of Baade's original postulate and the bold generalization from globular cluster population to universal population lent strength and beauty to his fundamental move. There was, of course, at the very beginning, the basic question whether the two populations were unrelated or, perhaps, two (possibly extreme) samples in a continuous sequence of types. For Baade, if I remember well, in the beginning this was not at all obvious, but at the time of the conference he accepted it.

At the Vatican Conference, simplicity gave room to a complexity of considerations: not only photometric properties contributed, also kinematics and spatial arrangement of the stars and interstellar matter in galaxies, understanding of main features of galactic dynamics, and, pervading all considerations, the rapidly developing understanding of stellar evolution. The scheme thereby became much more complex than Baade's original one.

The only deviation from using photometric criteria, Baade's reference to the "high-velocity stars" in the Galaxy as a representative of population II, goes back to early work by Oort preceding the discovery of differential galactic rotation. "High-velocity stars" were those with velocities exceeding 63 km/sec with respect to the local standard of rest, exhibiting pronounced asymmetry in the directions of their space-velocity vectors. We now interprete this asymmetry as due to these stars' deviations from circular motion around the galactic centre and therefore, in their mean motion, lagging behind with respect to stars in circular orbits. In the first of his 1944 papers Baade states that among them: *"(1) stars belonging to the upper main branch of the ordinary H-R diagram (highly luminous O- and B-type stars) are practically absent [...]; (2) the mean absolute magnitudes of dwarfs of a given spectral type seems to be the same for high- and low-velocity stars; (3) the relative proportion of dwarfs to giants is much higher among the high-velocity stars [...]; (4) the percentage of double stars is two or three times lower."* Indeed, we are dealing then with stars we now assign to an older disk population.

As to Baade's reference to *"our spiral arm"*: at that epoch, there was no notion yet of spiral structure as a passing feature, i.e. a wave-like one in which we are not permanently located. Since the early 1950's there was evidence, particularly due to the work by W.W. Morgan and associates based on the distribution of OB stars and subsequently from 21-cm neutral hydrogen observations, that spiral structure occurred in the domain around the sun, and that a spiral arm could be identified in which we are located. But this was considered as an, at least, semi-permanent feature.

2. The Vatican Conference

As early as in the late 1930's, the Vatican Academy intended to organize *"Semaines d'Etude"*, Study Weeks, for the purpose of discussing in depth areas of research where divergent opinions required the bringing together of experts, and thus to achieve clarification and planning of new avenues to follow. Plans for a first Semaine, on astronomy, had to be cancelled by the outbreak of the Second World War. Once they were resumed, the fourth Semaine was dedicated to astronomy. Planning was taken up by the Director of Vatican Observatory, D.J.K. O'Connell, during the 1955 IAU Assembly at Dublin. The topic Stellar Populations was an obvious choice: the subject embraced almost all aspects of astronomy and therefore required a wide variety of experts, and no broad discussion had taken place yet. 21 astronomers participated in 12 half-day sessions. The proceedings were edited by O'Connell and published in 1958 as Volume 16 of Pontificiae Academiae Scientiarum Scripte Varia under the title *"Semaine d'Etude sur Le Problème des Populations Stellaires"*, and also as a publication *"Stellar Populations"* of Vatican Observatory. I shall refer to it as "SP".

The programme listed a wide range of topics, but did not schedule the formulation of a new classification to replace Baade's scheme. This emanated from the discussions, which were somewhat of a brainstorming nature. Table 3 represents the new Population Scheme, adopted in the concluding session of the conference (SP, p. 533). It differed from Baade's scheme in that the category Disk Population was inserted between Populations I and II, and moreover, each of these latter two was subdivided into two categories so that the final scheme became: Halo and Intermediate Population II, Disk Population, and Older and Extreme Population I. Note that the time scale handled at the time of the Conference (1957) was still one assigning 6 billion years to the oldest population. It changed into about twice this number in subsequent years.

3. The New Insights

The most important developments preceding the Conference were the determination of accurate colour-magnitude diagrams of open- and globular clusters, and the work on stellar evolution based on the new understanding of stellar energy sources that provided first successful explanations of these diagrams.

Photoelectric photometry by Eggen and Johnson, superseding photographic work on colour-magnitude diagrams, revealed differences from cluster to cluster that would become a challenge for the theory of stellar evolution. Typical are the c-m diagrams shown by Sandage at the Vatican Conference (SP, pp. 42,43) and since then reproduced numerous times in the astronomical literature. For the nearest open clusters the data extended down to well below the turn off point from the main sequence. For globular clusters, however, (M3, M13, M92), the exact position of the turn off point was not yet well known and this implied great uncertainty in the age estimates. Broadly, there seemed to be three categories: the open clusters, ranging from NGC 2362 down to the Hyades, Praesepe and NGC 752, and exhibiting the gradual shift of their turn-off point downward along the main sequence (and understood in terms of increasing age); the (old) globular cluster pattern; and M67, suggesting an age comparable to that of the globular clusters but an initial heavy element content more like the open clusters.

Also since around the year 1950, it had become generally accepted that star formation is a continuing process, and that the youngest products of star formation, still in close association with the interstellar medium, are the youngest clusters and stellar associations. An example is the very young cluster NGC 2264, for which the scattering of points above the main sequence at its fainter end as found by Merle Walker was understood in terms of the pre-main sequence tracks.

The Vatican Conference was held a decade after nuclear physics had been introduced into astronomy, and consequently the study of stellar constitution and evolution had undergone a drastic change. It had brought reasonable understanding of the earliest phases of stellar evolution. (First with the work of Chandrasekhar and Schönberg on structure and evolution in the most inner part of the star, and then the work of Hoyle, Schwarzschild and Sandage on the subsequent evolution, to mention only some prominent names). Phases of the evolution more or less understood included, broadly speaking, initial contraction and gravitational energy release, rotational instability, early mass loss and T Tauri stage, core hydrogen burning, main sequence stage and the subsequent different evolutions for light (< 2 solar mass) and heavy stars: shell hydrogen burning surrounding the helium core

https://doi.org/10.1017/S0074180900108393 Published online by Cambridge University Press

in the former, core helium burning and shell hydrogen burning in the latter.

The new interpretation of the CM diagrams was one of the great accomplishments of post-World War II astronomy. It revealed that the majority of open clusters had ages up to several hundreds million years except for the much older M67, whereas those of globular clusters had to be counted in billions of years. Fitting of the observed CM diagram with computed isochrones moreover revealed that the old globular clusters had a metal content not exceeding one tenth of that of the young open clusters.

It also was known that the giant branch is the result of the funnelling of tracks of a range of masses, corresponding to spectral types B7 to F7, and that it therefore represented a population with ages between 0.5 and 5 billion years. However, the more advanced stages of evolution were still unclear. Did horizontal branch evolution proceed from left to right or right to left? How important was mass ejection in the post-main sequence stage? All that was known of He abundances was based on spectroscopy of a few stars; a standard assumption including the Sun was a weight abundance of about 0.25 (and 0.02 for the heavier elements), but there was no clue to the origin of this abundance.

There were indications that the oldest galactic clusters contained white dwarfs whereas that was not the case for young clusters. It was suspected, but by no means well understood, that red giants, after traversing the horizontal branch, proceeded to the white dwarf stage, a process possibly accompanied by nova outbursts. The evolutionary stages represented by planetary nebulae, novae, supernovae, Carbon and S stars were still unclear; yet these stages were classified in the Vatican population scheme, but on the basis of different criteria, like spatial distribution in the Galaxy or kinematic properties.

Galactic dynamics had provided explanations for the interrelation between some of the parameters that would play a role in the allocation of objects in the population scheme. Well understood was, first of all, the relation between the velocity dispersion of a given category of stars – more specifically the velocity dispersion perpendicular to the galactic plane – and the thickness of the "layer" of these stars in the region around the sun. It therefore was a safe step to infer this thickness from the well measured velocity distribution. Known velocity distribution, and in particular the *"asymmetric drift"* (the measure of a group's lagging behind the circular velocity of galactic rotation) allowed an estimate of its radial galactic density gradient. Thickness of the layer and density gradient thus obtained from kinematic data formed important parameters for the population classification.

On the other hand, understanding of galactic evolution was still very rudimentary. It was generally assumed that it might be subdivided into

https://doi.org/10.1017/S0074180900108393 Published online by Cambridge University Press

TABLE 1. Schwarzschild's Age Sequence (SP, p. 212)

Population	Typical members	Age#	Heavy elem. Z	VD*	Subsystem
Young Pop. I	young galactic clusters	0 – 1	0.04	10	flat
Interm. Pop. I	"strong-line stars"	1 – 3	0.03	20	
Old Pop. I	"weak-line stars"	3 – 5.5	0.02	30	interm.
Mild Pop. II	"high-velocity stars"	5.5 – 6	0.01	50	
Extreme Pop. II	globular clusters	6 – 6.5	0.003	130	spherical

Age in billion years *VD = velocity dispersion in km/sec

two stages: a first, contracting one with decaying turbulent velocities, followed by one with approximately constant velocity dispersion in a disk-like configuration. Of these, the first one was estimated to proceed rather fast, within the first one billion years, leaving 80 percent of the time scale then adopted for the later evolution.

4. Introduction of the Disk Population

As far as I have been able to trace back developments, the notion of the Disk Population as a separate category arose during the Conference, and appeared explicitely in a table drawn up by Oort, see Table 2 (from SP, p.419). It did not yet figure in a scheme mentioned by M. Schwarzschild in his book *"Structure and Evolution of the Stars"* which appeared in 1958, and in his Conference paper (SP, p.204). This is reproduced in Table 1. (The appearence of Schwarzschild's book just at the time of the Vatican Conference is a happy coincidence for the historian who wants to understand the status of stellar evolution studies at that particular epoch. Useful for this review has also been this author's chapter on Stellar Populations in the Compendium Stellar Systems, Vol. V Galactic Structure, editors A. Blaauw and M. Schmidt.)

It was well known from dynamical as well as purely observational considerations, that a considerable fraction of the mass of the Galaxy had to be assigned to a disk-shaped component. In a first paper at the Conference, Baade had pointed out that the Andromeda disk, which carried the most conspicuous elements of population I, also contained *"an overwhelm-*

https://doi.org/10.1017/S0074180900108393 Published online by Cambridge University Press

ing majority" of ordinary red giants of absolute magnitude 0 – not the much brighter giants of the globular cluster type – similar to the situation in the disk of our Galaxy. In Baade's second paper at the Conference, he outlined properties of the galactic disk which were the main incentive for assigning to it the separate role in the population scheme. He pointed out that plots of novae and planetary nebulae *"[...] show at a glance that [these] form the kind of flattened system that we would expect for the disk of the Galaxy."* Moreover, these objects show strong concentration towards the galactic nucleus. Baade assigned these to population II and concluded that *"in the Galaxy the population II is not only present in the spherical halo but also in the galactic disk. But while the population II makes up the entire halo it is [...] only one of the populations of the galactic disk."*

Additional evidence for assigning to the disk its central role in the scheme, was based on statistics of globular clusters and on statistics of variable stars. With reference to earlier work by W.W. Morgan, W. Becker, and N.U. Mayall, Baade pointed out that globular clusters with integrated spectral types A5 to G0 show little concentration to the plane of the Galaxy, whereas those of types G3-G5 are strongly concentrated to the plane. He thus suggested the subdivision of globular clusters into a "Disk Population" and a "Halo Population". The former exhibited "normal" metal content and therefore in their physical make-up were much closer to the open cluster M67 than to the "halo globular clusters". Furthermore, the c-m diagram of stars in the solar neighbourhood was found by Eggen to resemble strongly that of M67, thus confirming that this cluster could be considered as a representative of the local old stars population.

Baade's work on variable stars in the direction of the galactic centre suggested the occurrence of a population of RR Lyrae variables with a frequency maximum at 0.3 days which must be characteristic for the nuclear region of the Galaxy – distinct from the "normal " population of RR Lyrae stars in the halo for which the periods exceed 0.3 days.

The first proposal at the Conference for a revised scheme (see Table 2) still discriminated within the Disk Population two subdivisions represented by stellar types that differed somewhat in thickness of the system, 450 and 300 pc, respectively, with the planetary nebulae and the novae in the former category, and the weak-metal line population in the second one, and with age estimates of 5, and 1.5 to 5 billion years, respectively. The final discussion decided to amalgamate these into one category.

5. The Vatican Scheme Reviewed

We now briefly review the Vatican scheme and, for the various samples mentioned in Table 3, note the criteria that led to their classification. Apart

https://doi.org/10.1017/S0074180900108393 Published online by Cambridge University Press

TABLE 2. Oort's Proposal

Halo Pop. II	Interm. Pop. II	Disk Pop. II	Transition Pop. I-II	Interm. Pop. I	Extreme Pop. I

TABLE 3. Adopted Classification

Population	Mean z pc	Mean Z km/s	Typical members
Extreme Pop. I	120	8	Gas, Young stars associated with spiral structure, Supergiants, Cepheids, T Tauri stars, Galactic Clusters of Trumpler's Class I
Older Pop. I	160	10	A-Type stars, Strong-line stars
Disk Population	400	17	Stars of galactic nucleus, Planetary Nebulae, novae, RR Lyrae stars with periods below 0.4 days, Weak-line stars
Interm. Pop. II	700	25	"High-velocity stars" with z-velocities exceeding 30 km/sec, Long-period variables $<$ M5e with periods below 250 days
Halo Pop. II	2000	75	Subdwarfs, Globular clusters with high z-velocity, RR Lyrae stars with periods longer than 0.4 days

from the classifications assigned already by Baade, criteria now could be: a) photometry interpreted through stellar evolution, b) kinematic information (velocity with respect to the local standard of rest), c) space distribution, and (b) and (c) connected by galactic dynamics.

For most of the objects of Extreme Population I, their close association with spiral structure made this classification – quite in the spirit of Baade's original work – unambiguous. For the open clusters this also was the main argument. For Older Population I, kinematic information and space distribution was decisive. In the category Disk Population, kinematic and distributional information was decisive for the weak-line stars; for the remaining four categories, stars of galactic nucleus, Planetary Nebulae, Novae and RR Lyrae stars with short periods, it was mainly the space distribution (a flat system with strong concentration toward the centre). For category Intermediate Population II, it was mainly the kinematic information. For Halo Population II, it was, of course, Baade's use of the globular clusters in defining the category that made the classification obvious. For the RR Lyrae variables, both the association with globular clusters and their kinematics (high velocities) fixed the classification. For the subdwarfs it was the kinematics and the spectral properties.

6. The New Picture of Galactic Evolution; Later Developments

Oort, after having proposed the new classification, initiated a discussion on the evolution of the Galaxy, including references to contributions by Spitzer and Hoyle and to earlier discussions at the conference. For particulars I refer to the Report (SP).

Rapid progress in the areas the Vatican Conference dealt with followed in subsequent years. I shall mention a few only, reaching into the early 1960's. The c-m diagram of the open cluster NGC188 published by Schwarzschild in 1962 revealed its high age, and moreover this diagram agreed well with the lower envelope of the nearby subgiants, revealing their oldest Population I character. Emphasis was on measurements of chemical abundance parameters, combined with studies of kinematics and space distribution. Work by Kinman, published in 1959, on spectral properties of globular clusters confirmed the existence of two groups, those with weak metal lines and mean distances from the galactic plane between 5 and 6 kpc, and those with strong metal lines with mean distance about 2 kpc. Nancy Roman's work on the strong-line and weak-line stars among the bright star population, reported at the present conference, was followed up by quantitative measurements of metal-abundance parameters. Among these was Strömgren's work on the metal abundance parameter defined in the context of his u,b,y, photometric system and applicable to late F and early G stars, and Preston's quantity ΔS measuring the metal deficiency in cluster-type variables, published in 1959 and 1961.

Of an immediate bearing on the problem of galactic evolution was the work by Eggen, Lynden-Bell and Sandage, published in 1962, who plotted the uv excess of G dwarfs against their velocity component perpendicular to the galactic plane. This lent strong support to the collapse hypothesis, according to which the earliest star formation, at large distances from the galactic plane, occurred with much lower metal abundance than the more recent one at small distances from the plane. The evolutionary time scale meanwhile had rapidly grown from the 6 billion years still used at the Vatican Conference, to estimates between 10 and 15 billion years for both the oldest population I stars and the Hubble time scale.

OSTERBROCK: I agree with Adriaan Blaauw that although Baade said long afterwards that George Gamow had sent him the correct interpretation of Populations I and II soon after he published his 1944 paper, he did not fully accept it until a few years later. He certainly discussed "stellar evolution" as the difference in a 1947 letter to Fred Whipple. He did not mention it in his 1947 AAS paper at Columbus, the published form if his 1948 lecture at the Palomar dedication, nor the published form of his paper given in the summer 1950 (*after* his Princeton lectures) at the dedication of the H. D. Curtis Schmidt telescope at the University of Michigan. According to notes taken by the graduate students and postdocs who attended his lectures in the 1953 summer school at Michigan, he did give this interpretation there – but his letters show he was skeptical about some of those taking the notes! He certainly had accepted it fully by his 1958-9 lectures at Harvard, after the Vatican Symposium, held in the spring of 1958.

VAN DEN BERGH: What can you say about the relation between the Vatican's Intermediate Population II and the modern concept of the "thick disk".

BLAAUW: I find this difficult to answer, beacuse I am not quite up to date what "thick disk" nowadays implies. But as far as the "thickness" is concerned, this seems to be identical between the two, some 400 pc, in the region around the Sun.

FABER: What did the Vatican astronomers think of populations in the centers of galaxies, or in Baade's window at the center of the Galaxy?

BLAAUW: There was, if I remember well, very little discussion of the central region. Baade made his first attempt toward penetrating into this region by means of his variable star window. One did not yet speak about the "bulge" of the Galaxy, there was no infrared data and radio data yet...

TAYLER: I think that it is worth mentioning the position with regard to stellar evolution calculations in the mid 1950's. I do not believe that at that time there had yet been any fully self-consistent calculations with the correct opacities, chemical composition, equation of state, etc. This certainly affected the estimated ages. The 1960's was the decade in which the real models were first made. Probably this was one reason why Baade doubted the theoreticians.

BLAAUW: What were the reasons for the doubling of theoretical ages of clusters between then and now?

TAYLER: I am not certain precisely what caused this. However, it was certainly a matter of building appropriate stellar models for the problem in hand. I remember my own calculations being used to get ages for Galactic and globular clusters when they really only referred to stars of one mass.