# WALTER BAADE'S DISCOVERY OF THE TWO STELLAR POPULATIONS

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## 1. Introduction

Walter Baade was born one hundred and one years ago; he died in 1960, a third of a century ago. In my opinion he was the second most important observational astronomer of this century, after Edwin Hubble, who changed our place in the universe and our perception of it. I will give some of the evidence in this paper.

I believe that Baade's diagram of the two stellar populations is the second most important astronomical diagram of this century. It opened up the whole fields of stellar evolution and galactic evolution, as Hubble's velocity-distance diagram opened up the study of the whole universe.

In this paper I will first sketch Baade's life and scientific career; then describe his concept of the two stellar populations and how he developed it; then compare and contrast Baade with Hubble; and end with two "snapshots", dichotomies, or "bullets" which, I think, will help you to understand Baade.

One overriding principle is that all of Baade's life and research experience prepared him for his great discovery of the two stellar populations.

## 2. Baade's Career before World War II

Baade was born in Schröttinghausen, a very small town in northwest Germany. His father was a school teacher and Baade was well educated from childhood. As a student in the Gymnasium in Herford, he learned German, English, French, Latin, Greek and Hebrew, and could read them all (and did). Baade claimed that his parents raised him to study theology,



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but he was given to overstatement and never let a hard fact get in the way of a good story; actually, he was also very well prepared in physics and mathematics.

After finishing the Gymnasium in 1911, Baade became a student at the University of Münster for one year, and then at Göttingen University (the German equivalent of Harvard at the time) for six years. Baade was born with a congenital hip defect, which made walking difficult for him, and running impossible; this saved him from the German Army in World War I. From 1916 to 1918 he worked full time in an Army Technical Center in Göttingen (headed by Ludwig Prandtl, the hydrodynamicist) and studied in the time he had left over. Baade was an assistant in mathematics from 1915 to 1919, and had among his teachers Felix Klein and David Hilbert. Baade did his thesis on the spectroscopic binary $\beta$ Lyrae under Johannes Hartmann, and another of his professors was Leopold Ambronn; thus he was very well prepared for a research career in astronomy when he got his Ph. D. in 1919 (Schmidt-Kaler 1994).

You must remember that 1919 was not 1994! The largest operating telescope in the world was the Dominion Astrophysical Observatory 1.8-m reflector (since 1917); before that the largest had been the Mount Wilson 1.5-m (from 1908). The Mount Wilson 2.5-m went into operation in 1919. Telescopes were small, and the detectors, photographic plates, were slow and "ugly". Astronomers were few; there were only about 350 members of the American Astronomical Society in 1920, compared with more than 5,000 today. Astronomers were learning the *properties* of stars. They did not know the energy source of stars, they thought there was one "composition" which applied to all stars, they knew nothing at all about stellar evolution, and practically nothing about interstellar extinction.

Baade was especially interested in astrophysics. He wanted to go to America and work with the big telescopes immediately, but this was not possible for a citizen of defeated Germany in 1919. Instead he got a job at Hamburg Observatory, whose 1-m reflector (at Bergedorf, outside the city) was the largest telescope in Germany. Baade was extremely bright, and quickly made himself an expert observer; he was soon placed in charge of the telescope. Richard Schorr, the director, was an old-school astronomer who wanted Baade to concentrate on positional measurements of stars and asteroids; Baade's extremely pleasant personality enabled him to coax Schorr into letting him spend some time on the globular-cluster, star-cloud, and galaxy research he preferred himself.

Baade accompanied Schorr on an expedition to observe a total solar eclipse in the North Atlantic Ocean in January 1925. The ship put them ashore in the United States, and in the ten days they were there Baade met several American astronomers, including Harlow Shapley, whom he had first

met in Germany in 1922, and with whom he had been corresponding on globular-cluster research. Shapley, director of Harvard College Observatory, helped Baade obtain a Rockefeller Fellowship to spend a year in the United States, 1926-27, during which he worked at Harvard, Yerkes, Lick, DAO, and (most of the time) Mount Wilson. He did good work, chiefly on globular clusters, but some on spiral "nebulae". Everyone liked him; no one could consider him an enemy. He learned a lot about using big telescopes.

After his return to Hamburg Baade was promoted to Observator, the top staff member and traditionally the heir apparent to the Directorship. In 1928 he was offered an Associate Professorship and the Directorship of the Jena University Observatory, which had only a small telescope and no modern research equipment, but turned it down (Heckmann 1961).

Schorr, rejoicing at Baade's decision, and wishing to keep him at Hamburg, recommended him for a raise. At the same time Baade applied to the Hamburg faculty for his "Habilitation", his authority to teach in the university. This was granted and he gave his inaugural lecture on January 30, 1929, on *"The Extragalactic Nebulae as Star Systems"*, the subject of much of his future research (that was not on "Our Galaxy as A Star System"!) However, though Baade was allowed to teach, he did not get the raise, nor did he in 1930, when Schorr recommended him for a professorship.

In 1929 Baade led the Hamburg Observatory expedition to the Philippine Islands to observe the total solar eclipse of May 9, taking Bernhard Schmidt, the optician, with him. They went by ship and were gone from Hamburg nearly five months. Schmidt was the outstanding astronomical mirror maker in Germany, and no doubt on their long voyages out and back, Baade discussed with him for hours the need for a wide-field, reflecting (and hence achromatic) photographic telescope. Later that same year Schmidt came up with the idea of using a *spherical* mirror, removing its spherical aberration by a thin corrector plate at the center of curvature. By 1930 he had produced, tested and demonstrated his first Schmidt camera (Wachmann 1960).

Baade continued his research with the Hamburg 1-m reflector, as much of it as he could on globular clusters, and including discovering and investigating several small, faint (and hence distant) clusters of galaxies.

From the beginning of this work he (like Shapley) regarded RR Lyrae variables (they both called them "cluster-type variables") as the markers of globular clusters. Baade found some of these variables on his plates *outside* clusters, and immediately switched to larger plates in order to find more (Baade 1922; 1926a; 1926b). He also found some in galactic-plane fields, and realized that interstellar extinction, which was just being discovered by Robert J. Trumpler, prevented deep space penetration in these regions (Baade 1927; 1934). Baade thus had the concept of the spherical population

of globular clusters *and stars* very early (Baade 1931).

In 1931 Baade was offered a position on the Mount Wilson Observatory staff, and immediately accepted it. Hubble had proved the importance of galaxy research, and obviously Mount Wilson needed more workers in this field. Few Americans had worked on clusters and galaxies; Baade's published papers, plus the impression he had made while at Mount Wilson on his fellowship, won the job for him. Everyone liked Baade's breezy, friendly, outgoing personality. His way of talking was loaded with American slang. He never seems to have been subject to the anti-foreign antipathy that more professorial-type Europeans sometimes encountered at Mount Wilson.

Baade plunged into galaxy and globular-cluster research with the big telescopes. He never got into the cosmological problem, but instead tried to study galaxies as individual cases. His working papers, preserved in the Huntington Library, are full of such investigations. Baade had brought the news of the Schmidt system to America with him, and was involved from the start in getting the 18-inch Schmidt on Palomar, which went into operation in 1936, and planning the 48-inch Schmidt, to be used in tandem with the 5-meter. Baade did excellent research on supernovae, supernova and nova remnants, and galactic structure. Much of his time he spent in trying to set up reliable methods to measure magnitudes accurately to very faint limits, by photographic photometry before photoelectric photometry was considered applicable to faint stars and galaxies. He also experimented with red-sensitive plates, to minimize interstellar extinction, and searched for the nucleus of our Galaxy with them from Mount Wilson (Baade 1939). He did not find it, but he did find several of the clearest regions near it, including "Baade's window".

## 3. Discovery of the Two Stellar Populations

Thus when World War II came to America, Baade was well prepared for his epochal discovery. Technically an enemy alien, he was barred from the wartime technical development work which took the younger astronomers away from astronomy altogether, and occupied much of the time and effort of the older ones on Mount Wilson's war project. Hence Baade, confined to Los Angeles County, had lots of observing time with the 2.5-meter in the West Coast wartime brownout. He already had very clearly the idea that the stars in elliptical galaxies would turn out to be "like" those in globular clusters, rich in cluster-type (RR Lyrae) variables and W Virginis variables (both of which he had studied for years), but without the luminous, blue stars that lie along the upper part of their Hertzsprung-Russell diagrams of galactic clusters and "normal" (our) regions of the Galaxy, or classical Cepheids. His work with Hubble on the "new stellar systems" in Sculp-

tor and Fornax, discovered by Shapley and his collaborators at Harvard on plates obtained with small telescopes in the Southern Hemisphere, but barely observable with the 2.5-meter at Mount Wilson, convinced Baade that these systems were dwarf elliptical galaxies (Baade and Hubble 1939). He thought that the more distant, elliptical companions of the Andromeda "nebula" were probably similar objects, and set out to test his ideas at the telescope.

Baade had experimented with red- and yellow-sensitive plates and with filters for years. He had the insight, the opportunity, and the necessary technical skills; he succeeded in resolving M32, the bulge of M31, its disk, NGC 205, NGC 147, and NGC 185, and thus demonstrating the two stellar populations. Baade also noted and described the very strong concentration of Population I, hot stars, H II regions and dust in the spiral arms of M31. His two papers (Baade 1944a; 1944b) spread the word and made him famous among astronomers.

Baade followed up with his probe for the nucleus of our Galaxy, using RR Lyrae variables as the tracers of Population II. Again, this study was barely possible from Mount Wilson with the 2.5-meter, and depended heavily on his technical skill (Baade 1946).

Thus by the end of World War II, Baade was the leader in the observational study of galaxies. He gave a major invited lecture on his work on the two stellar populations at the AAS meeting in Columbus, Ohio in December 1947. It made a tremendous impression on American astronomers, as did Baade's talk on *"A Program of Extragalactic Research for the 200-inch Hale Telescope"*, which he gave at its dedication (Baade 1948).

At that time Baade did not yet understand the physical cause of the difference between Populations I and II. He later said that George Gamow had sent him the correct explanation (on a post card!), that Population II stars are old and Population I stars young, almost immediately after reading the 1944 papers. Evidently Baade did not accept it at once. Henry Norris Russell (1948) first published the idea that Population II must be collections of old stars, in which the more luminous objects, with their short ages, had evolved away from the main sequence. But Lyman Spitzer and Martin Schwarzschild, and no doubt others, had known this since 1939, when the nuclear energy-producing chain reactions which transform helium into hydrogen were worked out by Hans Bethe. In fact, Spitzer (1941) had written a paper in which he divided the stars into essentially Baade's two populations, as *young, recently formed stars*, associated with the flat, disk-like distribution of interstellar matter, and *old stars*, with no high-luminosity supergiants left among them. This paper was the starting point of Spitzer's series of papers on the dynamics of interstellar matter. But two senior colleagues whom he asked to read the paper before he submitted it

advised him to remove this section, as they considered it "too speculative". He did so, and the published paper does not contain the table which clearly separated Populations I and II (although not under those names), but existing copies of the draft show that it was there originally.

Baade quickly grasped this age idea, accepted it, and stated it as the physical meaning of the two stellar populations at the 1952 IAU General Assembly in Rome (Baade 1954). He began working out its consequences himself with the 5-m Hale reflector and the 48-inch Schmidt. He started Allan Sandage, Chip Arp, and Bill Baum working on globular-cluster color-magnitude diagrams to date them, and himself continued exploring and comparing our Galaxy and M31, as well as supernova remnants and radio sources, until he retired at the age of 65 in 1958.

Then Baade gave a series of lectures at Harvard as a visiting professor (which were converted into a very influential book by Cecilia Payne-Gaposchkin after his death [Baade 1963]), another series of lectures at the Australian National University (where Bart Bok was the director), and returned to Germany in 1959. But his congenital hip defect caught up with him. His vertebrae had become intertwined and he suffered terrible pain. Baade underwent a serious operation in Göttingen, was hospitalized for five months, and died in June 1960. It is hard to remember now how much he changed astronomy!

## 4. Hubble and Baade

Edwin Hubble was only four years older than Baade, but he had been a member of the Mount Wilson staff for twelve years before Baade joined it, and he was already a famous astronomer in 1931. Thus Baade from the beginning was cast in the role of a junior to Hubble.

Hubble had begun his Mount Wilson career working on nebulae (including both real ones and galaxies) and then on the stellar content of galaxies. He had made very important contributions in both subjects, but by 1931 he was working almost entirely on the cosmological problem. Baade worked entirely on globular clusters and galaxies as individuals, and never touched the cosmological problem.

Hubble projected an imposing public image, liked personal publicity in the world outside astronomy, and did not have many friends among astronomers, nor get along well with them. Baade projected a personable, friendly, approachable image, disliked and distrusted personal publicity in the outside world, and got along very well with almost all astronomers. Hubble was good at attracting publicity and it furthered his career; Baade trying to hide from it, had several disastrous experiences with Rockefeller Foundation and Caltech flacks. In the end he was always disgusted with

the resulting stories.

Hubble was technically not a very good observer, but more than made up for it with his creative ideas; Baade was a superb technical observer who had extremely creative ideas too.

By the late 1930's Hubble was tired and less productive than in his earlier years; Baade was on an upward curve and never slid backward, at least before his retirement, and probably not before his final hospitalization. After World War II, which Hubble spent at Aberdeen Proving Ground as a high-level scientific administrator, he was definitely living in the past, and after his first heart attack (in 1949) he was a tired, sick man until his death in 1953, while Baade was a vital, exuberant, highly successful research worker at the center of the astronomical world. He gradually moved to the center of the stage, and of course took over fully after Hubble's death.

Yet Baade never clashed with Hubble. He never criticized Hubble or his work directly, but by giving his own views on the cosmological problem he did so indirectly. At Mount Wilson Observatory, Milton Humason and Baade got along best with Hubble, and represented him to the rest of the staff. It was probably better for Baade that Hubble spent World War II at Aberdeen, and was never an important factor afterward in the inner circle at Mount Wilson and Palomar Observatories, for it gave Baade the observing time he needed during the war, more than he would have gotten once it was over, and a larger voice in the Observatory councils. Hubble probably held Baade back from announcing what he understood of the two-population concept in their 1939 joint paper on the Sculptor and Fornax systems.

## 5. Baade as a Scientific Leader

Baade did not publish many papers, but he had an enoromous influence on the direction of astronomical research. His publications were like Gauss's, *"pauca sed matura"* (few but ripe). He had a tremendous amount of data, which he intended to work up and publish in retirement, but it was always more exciting for him to to open up a new subject than to do the final calculations and analysis, and write the final conclusions on subjects on which he had worked for years. (Some of this data was published by Arp, and by Henrietta Swope, Baade's assistant and collaborator in the years 1952-60, each naming Baade as a coauthor, and by T. van Agt).

But after World War II and the discovery of the two stellar populations Baade gave many invited lectures, and many extremely inspiring courses (beginning at Princeton in 1950, including among others two at Caltech, and ending in Australia in 1959). They were all attended by many faculty members and postdocs as well as graduate students. An example was the

Michigan Summer School of 1953 in which three of the four authors of papers in this historical session participated: Nancy Roman, Owen Gingerich, and myself. In personal correspondence and meetings Baade greatly influenced the direction of research of many outstanding astronomers, including especially Joel Stebbins (in his later years), Albert Whitford, Nicholas U. Mayall, and Gerald E. Kron in the United States. He encouraged many European astronomers, and he and Jan Oort constantly corresponded after World War II, stimulating one another's research. Baade was always prepared to discuss research at a deep level with astronomers who were actually doing it.

## 6. Baade and Theory

Although Baade was famous for his observational results, what he wanted was full physical understanding. In his early years he invented the "Baade-Wesselink method", a highly sophisticated astrophysical concept based on cyclical variations of velocity, radius, surface temperature and luminosity in variable stars. With his friend Wolfgang Pauli (when the latter was at Hamburg) Baade published a paper in 1927 on the radiation force on comets' tails, calculated for various molecules according to the then new quantum mechanics.

Once Baade realized that the two populations were really young stars and old, he threw himself into stimulating theorists into exploring and working out this field. He often recalled, as one of the most exciting experiences of his life, the atmosphere in Princeton in the spring of 1950, when he first gave a series of lectures on his results on the two populations, and Russell, Schwarzschild and Spitzer discussed theoretical interpretations of them. These included the degenerate-core, extended-envelope models of red giants, and the sweeping of gas out of spirals which then became S0's.

One of the last letters Baade received in the hospital in Göttingen before his death was from Willy Fowler, telling him about dating the universe from uranium-thorium abundances.

## 7. Conclusion

Walter Baade was a great astronomer and the father of the two stellar populations. A single person, he changed significantly the direction of astronomical research. Dedicated to it, he was fantastically interested in astronomy and worked hard to the end of his life. Baade was a supreme individualist who always sought astrophysical understanding.

## 8. Sources and Acknowledgement

This short paper is based on the historical research for a much longer biographical article on Baade's life and career which I am now writing. It will contain full references to many letters, memoranda, worksheets and other material in numerous archives which, in addition to the published papers listed in the references below, provided the original source material for this paper. I am most grateful to the Huntington Library, San Marino, California, for a research grant which enabled me to study the Walter Baade Papers, in the Mount Wilson Observatory Collection there.

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TRIMBLE: Baade being a modern man, did not speak of "Baade's window". He called it "Van Tulder's pole". Who was Van Tulden (given that we must be in his native country)?
OSTERBROCK: It is certainly true that Baade did not talk or write of "his" or "Baade's window"; he described it as the field with relatively low extinction at $l = 328^o, b = -4^o$.
BLAAUW: J.J.M. van Tulder was a student in Leiden. Oort instigated him to make a new determination of the Galactic pole position (and the distance of the sun from the plane). It is published in B.A.N. **9**, p. 315 (1942).
PAGEL: Baade was once asked by a lady journalist "Oh, Dr. Baade, if you had your life over again, would you still become an astronomer?" To which Baade replied: "Only if I could have an assurance that the ratio of absorption to reddening is constant!"
OSTERBROCK: This is a good story, which I have heard several times, but I have never been able to find it in print or in a letter from Baade. It certainly sounds quite a bit like the style of short, pithy, attention-catching statement he might have made.

HABING: Is it known that copies still exist of Baade's Harvard lectures, transcribed verbatim, before Cecilia Payne-Gaposchkin edited them, and removed some interesting comments on some of his colleagues, e.g. Kapteyn?
OSTERBROCK: Yes. There are also copies in existence in the U.S., and I have consulted them. Cecilia Payne-Gaposchkin, who brought about Baade's visit to Harvard for the fall semester 1958-9 to give these lectures, made sure that they were tape recorded, and transcribed, to serve as the basis of a book by Baade. After his death, she edited the notes for publication as the book, but removed all negative comments Baade had made on *the work* of other astronomers, which she considered inappropriate to be put in print.
TAYLER: I would like to add to your comment about Baade's reluctance to publish. I was in Pasadena with Martin Schwarzschild in late 1953. He had discovered evidence that M31 was distorted by one of its satellites and thought this was new. He mentioned it to Baade who said that he had known that for a long time. Schwarzschild then said to me that there was more unpublished work in Baade's desk than most people published in a lifetime and that it was necessary to get to Pasadena from time to time to look into Baade's desk.
KING: Don, another thing you might have mentioned is Baade's painstaking care with his observations and instruments. Once, in my working in the plate files, I ran across some 200–inch plates that were astigmatic. When I called this to the attention of Bowen, the Director, he said: "Oh yes, this would happen from time to time, but we would always find out about it at the time of Baade's next observing run."