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LUDWIG FRANZ BENEDIKT BIERMANN: THE DOYEN OF GERMAN POST-WAR ASTROPHYSICS

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Abstract: Ludwig Biermann was a major figure in theoretical astrophysics in Germany in the twentieth century. His work on stellar interiors, comets and magnetic fields advanced our knowledge. He also predicted the existence and the nature of the solar wind. His predictions were vindicated by space probes. Ludwig Biermann also was an important figure behind the scenes working on the revival of German astronomy after the demise of WWII. For his work he earned important national and international honors.

Key words: Ludwig Biermann, stellar interiors, comets, solar wind, Max Planck Institutes

1 INTRODUCTION

Ludwig Biermann (Figure 1) was born on 13 March 1907 in Hamm/Westfalia and died on 12 January 1986 in Munich at the age of 78 years. He is closely associated with the rise of German astronomy and astrophysics after the demise of WWII. Biermann made outstanding contributions to astrophysics and plasma physics for over fifty years.

Ludwig Biermann attended school in the Hammonese Gymnasium in Hamm/Westfalia where his interest in physics was aroused. He started his studies at the Technische Hochschule in Hannover, moving to universities in Munich and Freiburg before earning his doctoral degree in Göttingen in 1932. Biermann was influenced by Hans Kienle (1895–1975), who persuaded him to concentrate on astrophysics. Another important person to influence him was Ludwig Prandtl (1875–1953), who taught in Göttingen and was a pioneer of rigorous mathematic methods in applied science.

Biermann's doctoral thesis was titled "Konvektionszonen im Inneren der Sterne" ("Convection Zones in the Interiors of Stars"), defended at the Göttingen University in December 1932, and understandably his first publications dealt with stellar atmospheres. This was a glorious time to be carrying out such research with numerous charismatic astrophysicists developing the subject. In his early publications (Biermann, 1931a; 1931b; 1932a; 1932b) the question of convection in the interior of stars was discussed. Biermann applied rigorous mathematical methods to the solution of the models. A post-doctoral visit to St Andrews University in Scotland followed. This must have been the time when Biermann first made contact with Thomas George Cowling (1906–1990) who was working independently in a similar direction. A long-term friendship resulted from their correspondence.

The dramatic political changes in 1933 resulted in the departure of nearly half of the physics faculty of Göttingen University in view of the Nazi racial laws. The glorious days of Göttingen University were over, and a new era began. After returning from Scotland, Biermann joined Heinrich Friedrich Siedentopf (1906–1963), then the Professor of Astronomy in Jena. Here he presented his 'Habiltationschrift' (Biermann, 1935) a prerequisite for an academic post in a German university. In 1937 Biermann moved again, this time to the Babelsberger Sternwarte in Potsdam. This gave him many new contacts,

Figure 1: Professor Ludwig Biermann (courtesy: Astronomische Gesellschaft).

and also access to the Kaiser-Wilhelm-Institut für Physik with its broad range of research directions. In Potsdam Biermann also was in close contact with Karl Wurm (1899–1975) who worked in the Hamburg-Bergedorf Observatory and pointed out to him that there were problems in interpreting the observations of cometary tails. As a result of these contacts Biermann became interested in researching cometary phenomena, and this would develop into a major interest. Also in Potsdam was the Astronomisches Recheninstitut, where Biermann's first serious encounters with astronomical computing occurred. His life-long interest in computing possibly dated from these contacts.

Towards the end of WWII Biermann and his family had to leave Potsdam and move to a village near Detmold, then once the war was over his first contacts were with the Hamburg-Bergedorf Observatory. The foundation of the Max-Planck-Gesellschaft, as a continuation of the Kaiser-Wilhelm-Gesellschaft, took place in 1948, and Ludwig Biermann was asked by Werner Karl Heisenberg (1901–1976) to join the Max-Planck-Institut für Physik in Göttingen and build up a Department for Astrophysics.

Biermann (1951) predicted the nature of the solar wind, arguing that corpuscular emission from the Sun was needed to produce the tails of comets, and when he reassessed data from the 1910 passage of Comet 1P/Halley he found that they supported his predictions. The existence of the solar wind later was confirmed by satellite observations.

Another direction of research that Ludwig Biermann pursued with Arnulf Schlüter (1922–2011) was the study of the role of magnetic fields in the interstellar medium. The idea of the 'Biermann Battery', a possible mechanism for forming primordial magnetic fields, dates from these investigations. Several papers were published on the question of cosmic rays as sources of synchrotron radiation, and other directions of research were studies of crossections and oscillations in various atomic elements, and data needed to refine the computation of the radiation from stellar interiors. Most of this work was done in collaboration with Eleonore Trefftz (b. 1920).

In 1958 the Max-Planck-Institut für Physik was moved from Göttingen to Munich and became the Max-Planck-Institut für Physik und Astrophysik with Werner Heisenberg continuing as Director of the Physics Institute and Ludwig Biermann becoming the Director in charge of the Astrophysics Institute. Within the framework of the Max-Planck-Gesellschaft, as the leading scientific research organization in Germany, from 1958 Biermann became an important figure on the committees that decided on the development of German astronomy and astrophysics.

On the basis of Biermann's theoretical work, campaigns to create ionized clouds of strontium and barium in the Earth's atmosphere were pursued, starting in 1961. This research involved collaboration with Reimar Lüst (b. 1923), and numerous rocket launches were made which showed that the method allowed the study of the interactions between the Earth's ionosphere and the solar wind. This led, in 1963, to the foundation of the Max-Planck-Institute für Extraterrestische Physik (MPE), with Reimar Lüst as the inaugural Director. Meanwhile, Biermann's interest in plasma physics was in large part responsible for the founding of the Max-Planck-Institut für Plasmaphysics (IPP) in Garching. In addition, Biermann also was active in the foundation of the Max-Planck-Institut für Radioastronomie (MPIfR), in Bonn, in 1966.

Numerous space projects to study comets were actively followed by Biermann, even after his retirement, and he was involved in the very successful Giotto Halley multi-color camera project, which took place during the encounter with Comet 1P/Halley on the exact date of his birthday, but almost two months after he had died. Numerous awards, prizes and memberships of academies crowned his scientific career.

2 THE EARLY YEARS

Biermann's doctoral thesis and all of his early publications deal with the problem of stellar structure. The theory of stellar interiors was iniitated by J. Homer Lane (1819–1880), followed up by August Ritter (1826–1908) and Jacob Robert Emden (1862–1940), and then rapidly developed by Karl Schwarzschild (1873–1916), Arthur Stanley Eddington (1882–1944), Albrecht Otto Johannes Unsöld (1905–1995), among others. Biermann became fascinated by the theory of stellar interiors and made considerable contributions to its advance. His early publications (in German) appeared in *Zeitschrift für Astrophysik* and *Veröffentlichungen der Sternwarte Göttingen* (Biermann, 1931a; 1931b; 1932a). The development of the interior of a star with a point-like nucleus and stellar atmosphere was discussed in detail. In particular, the methodology of Ludwig Prandtl's 'mixing-length' was successfully applied by Biermann to the astrophysical problems of energy transfer from the interior of stars. The results of these early computations are valid even today. For the builders of models, the importance of convection for the energy transport was a great simplification. However, at the end of the discussions the point was made that the mechanism of energy production was unknown—this was some years before the work of Carl-Friedrich Freiherr von Weizsäcker (1912–2007) and Hans Albrecht Bethe (1906–2005) showed that nuclear physics could explain the source of energy in stars (see the Bethe-Weizsäcker-cycle). The work on convection zones in interiors of stars gave us an understanding of phenomena such as sunspots and the solar corona (e.g., see Biermann, 1932b). In his post-doctoral visit to St Andrews University in Scotland Biermann made contact with Cowling, resulting in extensive correspondence and later in a joint publication (Biermann and Cowling, 1940). In this publication the need to consider chemical elements other than hydrogen in the computation of energy transfer in stellar interiors is stressed. Also the realization of the need to include magnetic fields in the models was a result of this encounter.

This research by Ludwig Biermann was continued during his short stay in Jena, in the group of Professor Siedentopf, who also worked on stellar interiors. It was there that Biermann (1935) presented his 'Habilitationschrift', which was titled "Konvektion in Inneren der Sterne" ("Convection in the Interiors of Stars"). The importance of convection in cosmic objects became a sort of 'hobby horse' for Biermann, and later was very important in some of his astrophysical investigations.

When he moved to Babelsberg (Potsdam) in 1937 Biermann got involved in interpreting observations of stellar spectra (Biermann and Hachenberg, 1939). Biermann (1943a) became interested in oscillator strengths of the atoms Na I, K I and Mg II, which led to quantum mechanical computations. He also discussed the chemical composition of the Sun (Biermann, 1943b).

The war years did not affect Biermann's scientific output, although he had to get involved in the work of the Astronomisches Rechen-Institut in Potsdam. For Biermann these contacts were very important, as the development of computing methods—which was the main purpose of the Institut—obviously was needed for his research on stellar interiors.

3 THE BEGINNINGS IN GÖTTINGEN

Biermann's family lost their home during the bombing of Berlin, and they moved first to Brüntrup, near Detmold, and later to Göttingen where they were when the war ended. Biermann's first contacts were with staff at Hamburg University, which led him to spend a short time at the Hamburg-Bergedorf Observatory. Werner Heisenberg then managed to persuade Biermann to move to Göttingen and build up a Department of Astrophysics in the newly-founded Max-Planck-Institut für Physik (see Figure 2). Research on the high temperatures in the solar corona was followed by an important paper on the reasons for chromospheric turbulence of the Sun (Biermann, 1948). It also was at this time that a close collaboration was established with Eleonore Trefftz on the subject of cross sections, wave functions and oscillations of various elements found in stars. This was one step away from considering the hydrogen atom only in stellar interiors. The discussion that began with Unsöld's suggestion of an 'Ultrastrahlung' as the reason for cosmic radio waves emitted by the Sun also was taken up by Biermann and Bragge (1949) and Biermann et al. (1951b).

The concept of a solar wind was essentially implied by Eddington (1910) in his discussion of the Comet C/1908 R1 (Morehouse). However, no physical explanation was attempted at that time, other than to imply that cometary heads and tails must be formed by some interaction with the Sun. Biermann then discussed the 1943 observations of Comet C/1942 X1 (Whipple-Fedke-Tevzadze) made by Cuno Hoffmeister (1892–1968) in 1943 and proposed an interpretation. This work led to his most important prediction: that of the existence and the nature of the solar wind (Biermann, 1951). Biermann argued that solar radiation cannot inject sufficient momentum to make the ionic tails of comets, and that corpuscular plasma also was required. Biermann developed a scenario of the physical interactions that were necessary to produce the rapid changes in cometary tails, and when he examined the tail of Comet 1P/Halley in 1910 he found that it supported his predictions. This was the beginning of his life-long interest in comets and the solar wind. Meanwhile, in 1957 he provided a general discussion of the solar wind (Biermann, 1957), and his ideas were vindicated by satellite probes, beginning with Luna 1 in 1959. Details of the solar wind were observed by later space probes (e.g. Luna 2, Luna 3, Venera 1, Mariner 2 and Ulysses), and there was good agreement with the theoretical predictions made by Biermann.

Biermann's incursion into the study of magnetic fields resulted from correspondence with T.G. Cowling about the necessity of including

Figure 2: Ludwig Biermann at his desk in Göttingen, in about 1948 (courtesy: Archiv der Max-Planck-Gesellschaft, Berlin-Dahlem).

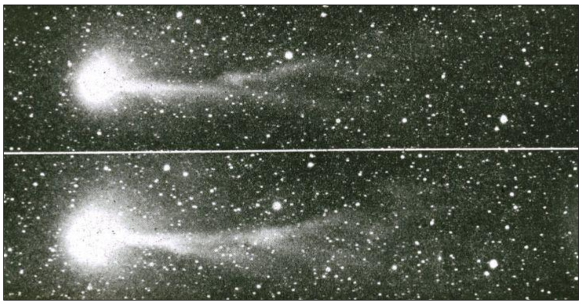

Figure 3: Two photographs of Comet C/1942 X1 (Whipple-Fedke-Tevzadze) taken just 1.776 hours apart showing the rapid development of the comet's tail (after Hoffmeister, 1944).

Figure 4: Heinz Billing with the G1 computer (courtesy: Astronomische Gesellschaft).

magnetism in stellar models. Cowling's 'antidynamo theorem' (1933) suggested that a rotating object like a star cannot generate a magnetic field, but Biermann (1950; 1952b) discussed the origin of cosmic magnetic fields in interstellar space and suggested a mechanism that would allow the creation of a magnetic field. Basically, in a plasma electric currents can flow due to charge separation, and this leads to a magnetic field. This mechanism has been named the 'Biermann Battery' (Mestel and Roxburgh, 1962). An interesting footnote is found in Biermann (1950), which says:

> A large part of the contents of the publication is a result of work carried out in 1939–1945 that have been put together in an unpublished report.

An appendix to the Biermann (1950) paper was published by Schlüter and Biermann (1950), and the clear implication is that the solution of Maxwell's Equations in the interstellar plasma is the way to handle cosmic magnetic fields. The 'Biermann Battery' was very important in any discussion of the origin of magnetic fields, a topic that was elaborated on by Biermann and Schlüter (1951). Their paper was the starting point for the later development of the Dynamo Theory by Parker (1955). This concept required convection in the interior of the rotating object. The possibility of such a scenario, the presence of forced convection in stellar interiors, was discussed by Biermann and Temesváry (1956). The Dynamo Theory, which requires seed fields (like the Biermann Battery), was first applied to explain the magnetic field of the Earth, and later was extended to explain the magnetic fields of the Sun and stars (e.g. Krause and Steenbeck, 1965; Steenbeck and Krause, 1966). The Dynamo Theory is widely used for the interpretation of magnetic fields in cosmic objects today, and it has even been used to account for the magnetic fields in galaxies (e.g. see Wielebinski and Krause, 1993).

Figure 5: The official opening of the MPI für Physik und Astrophysik in Munich-Freimann on 9 May 1960. Ludwig Biermann is second from the right (courtesy: Max-Planck-Institut für Astrophysik).

In addition to his main interests in comets and magnetic fields Biermann continued to collaborate on other projects of current interest in astrophysics. The origin of non-thermal radio emission, a lively subject at the time, was also considered and published by Biermann and Lüst (1957), and a return to the subject of stellar interiors led to a joint publication by Kippenhahn et al. (1958). For this work, computational programs were developed for the G2 computer that allowed the prediction of the evolution of giant stars. The collaboration with Leverett Davis Jr. (1914–2003) led to the development of considerations about the role of magnetic fields in the structure of our Galaxy (Biermann and Davis, 1960). In Göttingen, the Institute became known internationally for its studies of comets, plasmas and magnetic fields, with a very strong emphasis on computing in astrophysics, and Biermann gathered together a group of excellent collaborators: Arnulf Schlüter, Eleonore Trefftz, Reimar and Rhea Lüst, Rudolf Kippenhahn, Friedrich Meyer and Stefan Temesváry.

This interest in computing led to the appointment in 1952 of Heinz Billing (b. 1914; Figure 4), a pioneer in computing machines, who developed the G1 computer specifically to solve astrophysical problems. Billing's innovation, dating back to 1948, was the use of a magnetic drum memory. The G1 computer could make two operations per second, had a drum memory of 26 words each with 32 bits. The development of further computers, the G2 and the G3, followed. At this time no commercial electronic computers were available and Billing's work was state of the art. Billing had full support from Biermann, who saw in the development of computers a great potential for solving astrophysical problems.

4 THE MOVE TO MUNICH

In 1958 a move of the Max-Planck-Institut für Physik to Munich was completed. The new institute became known as the Max-Planck-Institut für Physik und Astrophysik, with Heisenberg and Biermann as Directors (Figure 5). At first the Institut was sited at Munich-Freimann, and later the independent Institut für Astrophysik moved with many other Max-Planck insitutes to Garching. With good support from the Max-Planck-Gesellschaft (MPG) many new possibilities opened up. One of these was the development of new computers (see Figure 6), first the G2 and later the G3. The latter computer had 4096 word memory, with 42 bits and a cycle time of 10 µsec. The G3 computer (Figure 7) was used for astrophysical problems by staff at the Max-Planck-Institut für Physik in Munich-Freimann until 1970.

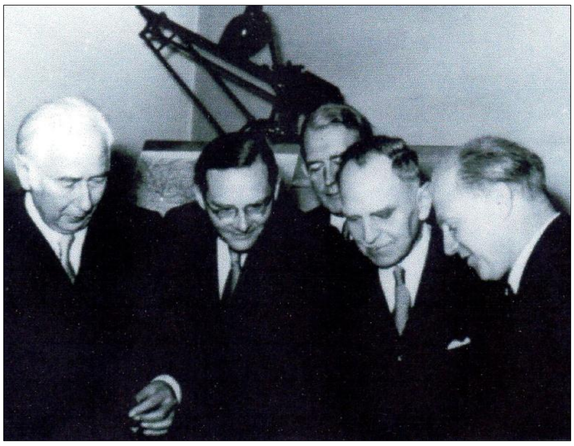

Figure 6: A photograph of the German Federal President, Theoder Heuss, inspecting the G1 computer in 1961. Those in front row (left to right) are: Theodor Heuss, Ludwig Biermann, Otto Hahn, Werner Heisenberg (courtesy: Astronomische Gesellschaft).

Working in another direction, the earlier studies of cometary tails, led to the suggestion of researching the interplanetary medium by creating artificial ion clouds. This proposal was made by Biermann et al. (1961) and led, ultimately, to the formation of the Max-Planck-Institut für Extraterrestrische Physik (MPE)—see Figure 8. The first experiments were performed in 1963 with strontium and barium clouds (see Figure 9) launched by rockets (see Föppl et al., 1967), and the evolution of the clouds in the Earth's magnetic field confirmed predictions made earlier by Biermann et al. (1961). However, Biermann personally did not participate actively in these experiments, which were left to other staff at the MPE.

The use of nuclear power for peaceful purposes was promoted at a large international conference in Geneva in 1954. Meanwhile, the Federal German Ministry of Science also decided to support fusion research, and Biermann's work on plasmas led to a discussion about the prospects for fusion. In 1960 the Max-Planck-Institut für Plasmaphysik (IPP) was founded (also in Garching) with very strong financial support (90%) from the Federal Government. One

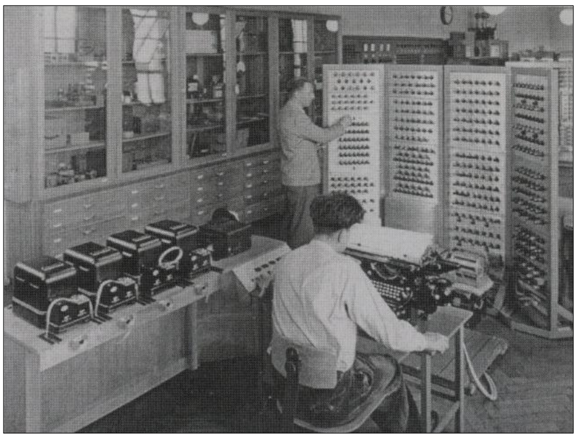

Figure 7: The G3 computing centre in Munich (courtesy: Astronomische Gesellschaft).

Figure 8: Ludwig Biermann (right), talking with the President of the MPG, Professor Adolf Butenandt, during the inauguration of the Max-Planck-Institut für Extraterrestrische Physik on 15 February 1965 (courtesy: Max-Planck-Institut für Astrophysik).

of the early Directors of the IPP was Biermann's friend Arnulf Schlüter. The IPP went on to develop many fusion experiments, first in Garching, later in the European JET experiment in Culham, U.K., and finally on an international scale at ITER, in Cadarache, France.[1]

Biermann's interest in magnetic fields led to his active participation in the foundation of the Max-Planck-Institut für Radioastronomie, and he visited several radio astronomy observatories in the USA in 1961, and the Sugar Grove project that was then under construction (e.g. see Figure 10). In July 1963 the author (Richard Wielebinski) was invited to give a colloquium about the detection of radio polarization in our Galaxy which was made at Cambridge and Dwingeloo

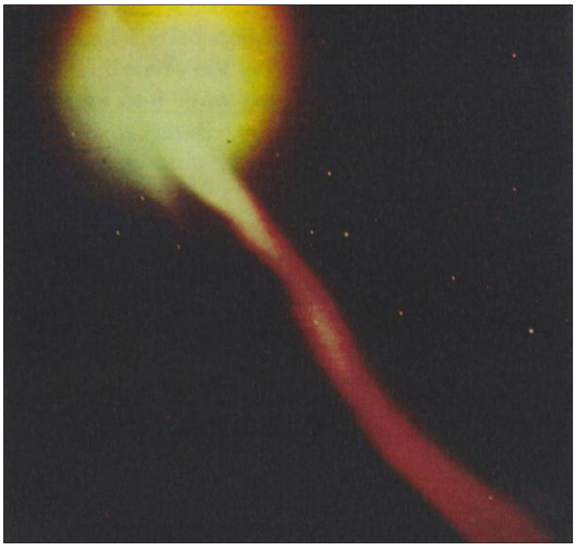

Figure 9: An artificial barium cloud injected into the ionosphere and glowing in the Earth's magnetic field (courtesy: Professor Dr G. Haerendel).

in 1962. This work was of great interest to Biermann since it finally provided proof of the existence of magnetic fields in our Galaxy. The founding of the Max-Planck-Institut für Radioastronomie, in Bonn in 1966, was due in part to the active support offered by Ludwig Biermann through different Max-Planck-Gesellschaft committees.

5 LUDWIG BIERMANN–THE 'COMET GURU'

Ludwig Biermann continued all the while to work in his major discipline, the study of comets. The interaction of the solar wind with a comet was treated in detail in Biermann et al. (1967). In this paper many details of the expected flow patterns were computed.

The mechanism of ionization in cometary atmospheres was discussed by Biermann and Trefftz (1967a). The discovery of huge hydrogen atmospheres around the heads of two bright comets, C/1969 T1 (Tago-Sato-Kosaka) and C/1969 Y1 (Bennett) by the Orbiting Astronomical Observatory (Code and Savage, 1972) was discussed by Biermann (1971a) in a review paper. The point was made that these space observations gave support to theoretical models that had previously been based on inferences or deductions, not on direct observational evidence.

Further research on the interaction of comets with the solar wind was presented by Biermann (1971b) in a symposium devoted to problems of magnetized plasmas, and held to honor T.G. Cowling. The observations of the ultraviolet 900 Å line and the 1216 Å Lyman α line were used to make a detailed interpretation of cometary physics. A commentary on Comet C/1973 E1 (Kohoutek) was given by Biermann (1973)—although it was a somewhat disappointing comet, it still provided important new data.

In his 1980 Karl-Schwarzschild Lecture to the Astronomische Gesellschaft Biermann reviewed thirty years of cometary research, and the resulting published paper (Biermann, 1981) was an important contribution to the history of cometary astronomy.

The presence of molecules in comets was discussed in Biermann et al. (1982). This work was based on the recent comet observations that allowed a close comparison with established theoretical models. The composition of a comet with an ice nucleus and numerous molecules was studied. Observations of comets and their evolution were considered, and scenarios of chemical kinematics also were theoretically investigated.

The aphelion clustering of distant comets, seen as star tracks in the Oort Cloud, was discussed by Biermann et al. (1983). In this work, the puzzling clustering of long-period comets was investigated. By this stage of his life, Ludwig Biermann was an unchallenged authority on comets.

In the last years of Ludwig Biermann's life two successful spacecraft designed to investige comets were launched. In 1977 NASA and ESA began a program of three spacecraft in the framework of the International Sun-Earth Explorer (ISEE) investigations. The International Cometary Explorer (ICE; ISEE-3) was launched in 1978, and on 11 September 1985 this spacecraft passed through the plasma tail of Comet 21P/Giacobini-Zinner at a point about 7,800 km from the nucleus. The era of 'fly-by studies' of comets had begun.

The last cometary research program in which Ludwig Biermann participated involved the multicolor camera that was flown past Comet 1P/Halley in 1986 (Johnstone et al., 1986). This camera was developed by H.U. Keller (b. 1941), one of Biermann's former students. This experiment, known as the Giotto Mission, gave unprecedented visual information during a close approach to the comet. During the night of 13–14 March 1986 Giotto came within 596 km of the comet and pictures of the nucleus were transmitted back to Earth. For the first time a detailed study of the chemical composition of a comet could be carried out but, alas, Ludwig Biermann—who had devoted much of his professional life to the study of comets—died two months before this historic event. Appropriately, Giotto's approach to Comet Halley took place on 13 March, Biermann's birthday.

6 SUMMARY

Ludwig Biermann was a charismatic figure in the post-war German astrophysics community. He was a very reticent person, always working quietly in the background, but with great success in achieving his visions. Through his active committee work several Max Planck Institutes were founded, and he certainly made an important contribution to the development of German science in general and to the German astronomical community in particular. The results of his excellent research work also left their legacy, and his work on comets, magnetic fields and the prediction of the existence and nature of the solar wind earned him many international honours, including the Bruce Medal of the Astronomical Society of the Pacific in 1967, the Gold Medal of the Royal Astronomical Society in 1974 and the Karl Schwarzschild Medal of the Astronomische Gesellschaft in 1980.

7 NOTES

1. The concept of ITER, a large international fusion facility designed to generate a new, cleaner, more sustainable source of energy, was launched at the Geneva Superpower Summit in November 1985. Initial participants were the European Union, Japan, the Soviet Union and the USA, with China and South Korea joining the collaboration in 2003. In 2005 it was agreed that the ITER facility would be constructed at Cadarache in the south of France.

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Figure 10: Professor Biermann (centre) with two technicians visiting the Sugar Grove radio telescope project in West Virginia in 1961. Note the construction towers in the background (courtesy: Hastings Pawsey and Miller Goss).

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