# Hermann Bondi (1919–2005)

Hermann Bondi was born in Austria, in a Jewish family which was not very orthodox. He recounts not seeing the need for religion from a young age. His great mathematical talent was clear even in school, and he was familiar with much of classical physics by the time he finished – the main obstacle to his high school diploma being Latin. His mother arranged a meeting with the famous English relativist and astronomer, Arthur Eddington, as a resulty of which he went to Trinity College, Cambridge in 1937. He was already interested in relativity, and was initially admitted as a 'commoner' – a full fee-paying student. The unique Cambridge system quickly recognised his abilities with financial support, which was just as well since his family business collapsed and his parents had to emigrate to the US, just in time to escape the annexation of Austria by Hitler's Germany which triggered the second world war. The war also meant that as a German speaking citizen of Austria in England, he now had the status of an 'enemy alien'. This meant being interned – a kind of house arrest, in a remote location – the Isle of Man. Later, many internees were moved to Canada. Amongst this group were Thomas Gold, (later famous for steady state cosmology, and identifying radio pulsars as rotating neutron stars) and Max Perutz who later won the Nobel Prize for elucidating the structure of the haemoglobin molecule.

The internment was lifted by 1941, and Bondi was pressed into the war effort to develop radar, where he was posted in the company of Fred Hoyle and Gold. One of his achievements in this period was a better understanding of the magnetron. This, now familiar to most people as it is the source of microwaves in ovens, was one of the crucial factors in wartime radar. Cambridge university had considerately awarded him a BA (inspite of his 'enemy' status!). His election as a Junior Fellow of Trinity college meant that he could carry out research independently, after the war. Afer four years he became a mathematics lecturer, a position which he held till 1954. This period was marked by his collaboration with Hoyle and Gold on the steady state theory of the universe. To him and Gold, it was appealing because the uniformity of the universe in space was enhanced by a uniformity in time. This might seem contradicted by the fact that the universe expands, but the daring proposal was that new matter (and stars, and galaxies) was created at exactly the rate needed to fill in the void created by the expansion, allowing for a steady state. This theory made clear predictions which could be tested against observations, particularly in the field of radio astronomy. While these tests remained the subject of debate for many years, the discovery of the cosmic microwave background radiation meant that most astronomers, Bondi included, abandoned it, and even the diehard adherents like Hoyle modified it into a quasi-steady state theory.

An important and influential astrophysical contribution by Bondi during this Cambridge period was his rigorous solution of the simplest possible model of 'accretion' – gas being attracted to a central body like a star, and being heated by compression as it flows inwards. While his work assumed spherical symmetry, it was modified to include the velocity of the central body with respect to the gas by Hoyle and Raymond Lyttleton; so all three names are associated with this process. Accretion is now one of the key processes every astrophysicist has to learn about.

In 1954, he took up a professorship in King's College, London, and soon after, attended a conference on relativity held in Bern, Switzerland, to mark fifty years of Einstein's proposal of special relativity in 1905 from the patent office in the same city. The great physicist, Wolfgang Pauli, presided over the meeting and one of the major topics of discussion was gravitational waves, whose nature was very unclear at that stage (see the review of Kennefick's book elsewhere in this issue). Bondi was fascinated by this problem, and attacked it with characteristic energy. Another characteristic is that he did not do it alone. His former student, Felix Pirani, joined him and they set up a vibrant group, from which a series of papers appeared on this topic, by different authors in different combinations. In his autobiography, Bondi describes himself as a compulsive talker and it seems clear that he enthused and encouraged many people who worked in this field. One student recalls the first lecture of his course at King's college. They waited for the ill-dressed employee who rushed in and cleaned the blackboard to make way for Professor Bondi– until they realised he was Prof. Bondi!

From the start, Bondi was suspicious of the simple-minded 'linear' theories. At a second meeting, in 1957 at Chapel Hill, US, he took part in the debates on the reality of linear theories of gravitational waves. Pirani is credited with focusing attention on the observable motions of freely falling particles in the field of such waves, described elsewhere in this issue – basically a pair of particles changes its separation as measured by light beams (as in LIGO) or with respect to a ruler. The famous 'sticky bead' argument emerged in this meeting, attributed to Pirani, Feynman, or both. The idea is that if one introduces friction between the free particles (beads) and the ruler, then surely heat will be generated as the particles oscillate, and this means the waves carry energy. Bondi took this up in a later paper at a quantitative level, so the argument sometimes carries his name as well. The basic style of Bondi's programme for the King's College group was to pose well-defined mathematical questions of physical relevance, which could still receive defintive answers. The series of papers carried Roman numerals, and went upto XIII in 1989! The most famous one is the seventh Bondi, H.; Van Der Burg, M. G. J.; Metzner, A. W. K. (1962). "Gravitational Waves in General Relativity. VII. Waves from Axi-Symmetric Isolated Systems". *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences* 269 (1336): 21.

This paper concentrated on the time-dependent gravitational field at infinity, carrying outgoing waves but keeping track of nonlinear effects very carefully. A 'sandwich wave' was constructed and it was clearly shown that the mass of the material interior to the wave (which again needed careful definition) would decrease by an amount directly calculable from the wave properties. This was a major technical achievement. Characteristically, Bondi lectured extensively on this well before the publication, which was rather slow. It was possible for a brilliant young relativist in Syracuse, Rainer Sachs, to generalise this work removing the assumption of axial symmetry, and bring out the full structure of the spacetime at infinity and its symmetries – this paper followed in the same year, 1962. Thus the symmetries are now known as the BMS (for Bondi–Metzner–Sachs) group. Another brilliant relativist at Syracuse, Ezra 'Ted' Newman, went on to work with Roger Penrose to come up with a more sophisticated, elegant and general approach for analysing the equations and the behaviour at infinity. Most modern work uses this Newman–Penrose approach, rather than the original formulation, but this only adds to the credit of Bondi and his collaborators. They climbed the mountain by a more difficult route!

These papers did not remove all worries about gravitational radiation. In particular, the possibilty that a binary system might not lose energy (and mass) and hence might not radiate anything was left open, as is clear from the last section of the paper, because the matching of the behaviour at infinity with the source was yet to occur rigorously. One interesting stylistic feature of these papers is that each section carries a separate authors list, a subset of the list at the beginning which has all the authors. Thus, Metzner gets full credit for his contribution for analysing the "permissible co-ordinate transformations". Another Cambridge product, S Chandrasekhar, followed the same practice even in a two author paper with his student Esposito. Interestingly, in reviewing Chandrasekhar's book on *Truth and Beauty* Bondi remarks. "I do not wish to deny that giving earlier discoveries such concise, elegant descriptions is enormously useful for subsequent workers, but evidently it did not contribute to the original discovery. Beauty may be an excellent guide in mathematics, but I doubt its value in physics." His mathematics was clearly very strong but quite classical and always a means to answer a physical question.

One contribution of Bondi which all physics teachers should be aware of is his innovative approach to the pedagogy of special relativity. It is contained in his book *Relativity and Commonsense* and goes by the name of Bondi's k-calculus. The beauty of this approach is that measurements of space time co-ordinates are carried out by radar, there is no room for rods, only clocks, and the symmetry of the Doppler effect plays a key role. This makes for a tremendous simplification and the Lorentz transformation appears in a few lines. Radio signals travelling at the speed of light from the ground to satellites and vice versa are the basis of the GPS present in almost all mobile phones today.

In 1967, when he was still very active in research, Bondi surprised even his close friends by taking up the leadership of the European Space Agency. This was the beginning of a long career of public service, which included being the Principal Scientific Advisor to the UK government first on defence, then energy, and finally environment. His diverse achievements include a report on river flooding and remedial measures to curb the same! It appears he was very effective in these roles which involved extensive travel and interaction with widely different groups of people, but also a quick grasp of complex technical issues and a talent for getting to the most important point. This certainly contradicts the popular image of a mathematical physicist as highly introverted and unsocial. During this entire period, he continued to work on theoretical problems when he could.

No account of Bondi would be complete without mentioning his long association with the British humanist movement, and with rationalist movements all over the world in general. When he visited Bangalore, his hosts were surprised to hear that his next stop was Vishakapatnam – the headquarters of an atheist society with which he had long connections. The following quote brings out this side of his life and beliefs. In a letter to the *Guardian*, Jane Wynne Willson, Vice-President of the British Humanist Association, added a footnote to his obituary: "Also President of the Rationalist Press Association from 1982 until his death, and with a particular interest in Indian rationalism, Hermann was a strong supporter of the Atheist Centre in Andhra Pradesh. He and his wife Christine visited the centre a number of times, and the hall in the science museum there bears his name. When presented with a prestigious international award, he divided a large sum of money between the Atheist Centre and women's health projects in Mumbai."

Bondi married Christine (a student of Hoyle at Cambridge) and they had three daughters and two sons. He appears to have found the time, energy, and motivation to live a full and varied life, spanning research at the highest level, academic leadership, technical and administrative roles at the national and international levels, and advocacy in society as a whole. One role which must have meant a lot to him was becoming Master of Churchill College in Cambridge in 1983. Surely, this was ultimate acceptance and recognition by a university and a society to which he came almost as a refugee from an enemy country forty-six years earlier.

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