Beatrice Muriel Hill Tinsley

Beatrice M Tinsley was very nearly unique among modern astronomers in having solved a fundamental problem as part of her PhD dissertation. Much of the rest of her tragically short career was spent in improving that solution and tracing out its implications for other areas of astronomy and cosmology. Let us meet Beatrice[1] first; then the problem and her solution to it, followed by the later lives of both the astronomer and the astronomical topic; and end with reference to one or two other astronomers (also, as it happens, women, and not including the author, whose dissertation on the Crab Nebula was perfectly adequate, but not pioneering astrophysics) who solved major problems early in their careers (*Box* 1).

Beatrice was the middle of three daughters of a family with roots in Wales (father Edward E O Hill) and Scotland (mother Jean Morton) and a deep appreciation of music and literature. She herself was a fine violinist and wrote, whether for fellow scientists or for broader audiences, with unusual clarity and a style that brings back her voice even now. That voice was distinctly one of New Zealand, for, in 1946, her father accepted the first of a series of positions in the Anglican church there, eventually settling in as vicar in the town of New Phymouth, on the west coast of North Island. He later moved on to a secular position as Lord Mayor of the town and gradually loosened his connections with the church, which Beatrice herself had left long before. Her mother predeceased her, and she was survived by her father, stepmother, sisters, ex-husband and two adopted children. The land where she grew up left a second trace beside the characteristic 'kiwi' accent. She nearly always wore her hair pinned firmly back and, when asked why, replied, 'the average wind speed in Wellington, New Zealand is 40 miles per hour.'

The three girls attended single-sex church and district-supported schools, as was the custom of the time and place. Despite this, her outstanding school record, and her early penchant for organizing her time strictly, Beatrice discovered boys fairly early, and was engaged at 17, but unengaged by the next year. She started at Canterbury University in Christchurch in 1958, receiving, after some dallying with chemistry and mathematics, a 1961 BSc and a 1963 MSc in physics. By the time she started her MSc work, she was already interested in cosmology, the large-scale structure and evolution of the universe, though her thesis was on 'Theory of the crystal field of neodymium magnesium nitrate', that is, in the field now called condensed matter physics. She was also already married to a fellow graduate (research) student, Brian Tinsley, who completed a PhD in atmospheric science at Canterbury.

Beatrice, now Tinsley rather than Hill, had begun high school teaching of physics, but had also been awarded a small scholarship, which she was allowed to take with her when Brian Tinsley accepted a position at the new Southwest Center for Advanced Studies in Dallas, Texas, where there was to be a lab for Earth and Planetary Sciences (for him), but also a group in theoretical general relativity (Einstein's theory of gravitation, applicable to cosmology) with whom she hoped to work. The Center eventually became

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[1] I shall adhere to a quaint old-fashioned custom of referring by first names only those people I know or knew well for many years.

part of the University of Texas at Dallas, and he remains part of it. Within months of their arrival, the Tinsleys had seen, first, the assassination of John F Kennedy and, second, the first of the 'Texas' symposia on relativistic astrophysics, later incarnations of which Beatrice attended as an invited speaker and honoured participant.

Meanwhile, however, the Center was not proving an ideal place for a PhD student wanting to study astrophysics and cosmology, and Beatrice became one of the first research students in the new astronomy department of the University of Texas at Austin, which Harlan Smith had just come from Harvard to chair. She was, not surprisingly, the first woman student in the group, and this undoubtedly played a part in her being allowed to tackle a very difficult problem, since 'obviously' it did not really matter whether she finished or not. Beatrice's original goal had been to compare observations of galaxies with the predictions of various cosmological models, in hopes of being able to answer classic questions like 'will the universe expand forever?' and 'what is the geometry of the cosmos?'

But, after some discussion with Harlan, Rainer Sachs (of the Sachs–Wolfe effect) and other faculty, she recognized a major barrier to this goal. Unless the galaxies seen at large distances (and hence as they were long ago) were exactly the same brightness, size, and other properties as galaxies here and now, the tests would not work. Cosmological effects would be washed out by evolutionary ones.

It had been the custom of other astronomers thinking about cosmology to assume that changes, if any, were small; but nobody really knew, because nobody had quite figured out how to calculate the behaviour with time of a galaxy consisting of a hundred billion stars or more. Clearly the computers of 1965 could not keep track of 10^{11} separated entities (nor indeed can modern ones), let alone follow their changes for billions of years. Solving the problem called for a clever new idea; and Beatrice came up with one. She divided the continuous life of a galaxy into 10 or 20 time steps or generations, allowing stars to form only at the beginning of each time step. And she divided each generation into about a dozen classes of stars, such that members of a given class were all about the same mass (for instance 1.2 to 1.5 times the mass of the sun, 1.5 to 3.0, and so forth).

This turned out to be the magic bullet, because all stars with about the same mass will have similar lifetimes, brightnesses, and colours (temperatures) and will host the same set of nuclear reactions, making about the same amounts of carbon, oxygen, iron, and other heavy elements out of the hydrogen and helium they began with. The stars that make most of the heavy elements have short lives, and so, before generation N+1 formed, the big stars of generation N could be assumed to have expelled their products in supernova explosions, while the small stars continued their contribution to the light of the galaxy.

This replacement of continua by time steps and mass classes was, of course, an approximation. Others in her first models were (a) instantaneous recycling (that is, all the heavy elements came out quickly), (b) constant initial mass function (that is, the proportion of stars in each mass class were the same in each generation), and (c) rapid mixing of the ejected heavy elements into the rest of the gas of the galaxy, without any inflow or outflow or lumpiness (homogeneous, one-zone, closed box approximation). Thus a particular model galaxy should be described by just four numbers : its total mass, the fraction of gas turned into stars in each generation, the mix of mass formed and the age of the galaxy. And the output could be given as the time-history of the luminosity, colour, chemical composition, and residual gas mass of the model. The first happy result was that models 10-15 billion years old tended to look a lot like real galaxies today.

Beatrice's thesis, published in 1967 and 1968, was quickly recognized by most of the astronomical community as a major advance. She had shown that galactic evolution was (a) calculable and (b) important. That is, galaxies really did look quite different, and by different amounts, in the past. Corrections for these changes would therefore be an essential part of trying to use galaxies to do cosmology, and she teamed up with colleagues elsewhere to make the effort. Their answer, that the universe did not contain enough ordinary matter to stop the expansion, was correct, though not quite for the right reasons.

Beatrice was invited to speak at major conferences and to work for weeks or months at a time at other institutions, including California Institute of Technology, Lick Observatory, and the University of Maryland (where we briefly shared an office; and very exciting it was, too!). But there were major problems. First, the Tinsleys had adopted a son, Alan, in 1966 and a daughter, Teresa, in 1968, whose care inevitably fell largely on her shoulders. Second, although Brian Tinsley was granted tenure, she was not offered a proper job on either University of Texas campus, but only office space and a 'hunting license' to try to bring in enough grant money to support her research. And third, slowly but surely, the conflict between science and family put strains on the marriage. She tried to save the situation by offering to start up an astronomy department at Dallas, but somehow they were not very interested, and colleagues began to suspect that Beatrice might be movable.

She received offers from the University of Chicago and elsewhere, and in 1975 accepted an associated professorship at Yale, where Richard Larson, with whom she had already carried out several projects that brought together his expertise in star formation and hers in how to put stars together into galaxies, was located. They also established a strong personal relationship, but never married. Brian Tinsley remarried following the divorce, and for some years, he and his second wife had custody of both children as well as their own younger ones.

At Yale, Beatrice began working with a group of graduate students and postdoctoral researchers and colleagues elsewhere on a range of topics in evolution of stellar populations and how these give rise to the galaxies we see. Many of the approximations in her first models were replaced by more exact treatments. A minor one was adding in evolutionary tracks (provided by the present author) for stars of different initial compositions that were important at different times in the life of a galaxy. More important additions clarified the difference between the lives of spiral and elliptical galaxies, giants and dwarfs. Both triumph and tragedy were, however, lurking around the corner.

In 1978, Beatrice was promoted to full professor, but, in the same year, diagnosed with malignant melanoma, conceivably the legacy of the exposure of her very fair English skin to the sunlight of New Zealand when she was still a small child.

She remained scientifically active until almost the end, dying in the Yale infirmary in late March 1981, where her astronomical colleagues had, with both happiness and sorrow, but always with enlightenment, been visiting and phoning her for the last few months.

Since then, the University of Texas at Austin has established an endowed Tinsley Professorship of astronomy, and friends have arranged for the American Astronomical Society to present a biennial Beatrice M Tinsley prize. The winners so far have all been people who achieved something fairly unexpected (as well as important) typically as a result of long, hard work, of which one can be fairly sure Beatrice would have approved. These include S Jocelyn Bell Burnell (1986, co-discoverer of pulsars), Raymond Davis, Jr (seeker of solar neutrinos, in 1994, long before his Nobel Prize), Antoine Labeyrie (1990, for development of optical intensity interferometry), Charles Alcock (2000, for successful completion of the MACHO search for gravitational lensing by stars and dark stellar-mass entities in the halo of our galaxy), and Robert Dicke (1992, who carried out a number of experiments in gravitation, testing several aspects of general relativity, in very different ways from how Beatrice once set out to test GR with galaxies).

What has become of the subject of galactic evolution? It is now a major branch of 21st century astrophysics. And it has become very much more complicated than Beatrice's first set of models almost 40 years ago. In particular, 'closed box' models have given way to a picture in which most large galaxies are gradually assembled by mergers of smaller 'galaxy parts', each of which has had a Tinsley-like history of a few generations of star formation with variable initial mass function, non-instantaneous recycling, and so forth. Indeed the current situation somewhat resembles an American-style Chinese restaurant menu, in which the theorist chooses an idea or two from each of many columns and puts them together to see whether the result looks like some category of real galaxy, now or in the past. Some do, some don't. The current main challenge is to work out the physics of various processes: How does the IMF depend on gas composition? How much gas will be turned into stars in a merger and how much thrown out? etc. An important part of the evidence for the importance of mergers came from the long observation of one small part of the sky called the Hubble Deep Field, which was organized by Robert Williams, who very appropriately won the 1998 Tinsley prize for this work.

Did anybody ever solve the cosmology problem? Yes, but not primarily by looking at distant galaxies, which we now study to understand how we got here. Instead, observations of distant supernovae, the cosmic microwave background radiation, x-rays emitted by clusters of galaxies, the bending of light by massive galaxy and clusters (gravitational lensing), and the amounts of helium and deuterium in the most primitive stars and gas have together told us that our universe consists of about 4% matter (mostly hydrogen and helium) like ourselves, 23% dark matter that does not participate in either chemical or nuclear reactions, and 73% dark energy, which is now accelerating the expansion of the universe that Beatrice had hoped to probe with distant galaxies.

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Box 1.

I promised you at least a glimpse of a couple of other women astronomers whose early work made a big difference in important parts of astronomy. The first was Cecilia Helena Payne, who became a Gaposchkin by marriage. Born in England (again!) in 1900, she completed a PhD dissertation at Harvard in 1925 which established two very fundamental things about stars. The first (immediately believed, perhaps even believed too much) was that nearly all stars contain almost exactly the same proportions of the various chemical elements. And the second, for which acceptance took more than a decade, was that the standard mix had hydrogen and helium as the major constituents. Notice that these results were essential input for Beatrice's work. Cecilia spent the rest of her career at Harvard, becoming the first woman appointed to a full professorship there in 1956 and dying in 1979. Her later work focussed on variable stars, including novae and supernovae, and she was among the first to recognize that even the ejecta from supernova explosions must consist of common elements (but not mostly hydrogen and helium!).

Cecilia had been the first recipient of the Annie J Cannon Prize (for women astronomers) of the American Astronomical Society in 1934. Curiously, after another very distinguished English-American astronomer, E(leanor) Margaret (Peachey) Burbidge refused the prize on the grounds that women were perfectly capable of competing with men for the regular ones and the Cannon Award was reconstituted as a fellowship, Beatrice was the first winner (at the same age, 34, as Cecilia had won it). Not surprisingly, Cecilia and Margaret were the first two women awarded the most important AAS prize, the Russell Lectureship. Margaret's most important work was done somewhat later in her career and included being part of a collaboration that established in 1957 how most of the heavy elements could be synthesized in stars of various types. Notice that this falls both logically and chronologically between the contributions of Cecilia and Beatrice. Margaret has also helped us understand the nature of the quasars and other active galaxies, part of a different set of problems.

The third woman Russell Lecturer, who (like Margaret, but unlike Cecilia and Beatrice) is still a very active member of the astronomical community, though nominally retired, is Vera Cooper Rubin. She is now best known for having measured the rotation speeds of a large number of spiral galaxies, thereby showing that their outskirts contain large amounts of dark matter. But her master's thesis, carried out at Georgetown University in the early 1950s, was the first glimmer of the now generally-accepted fact that the motions of galaxies deviate from smooth expansion on scales even larger than clusters of galaxies.

Would you like to know more about these astronomers? Then read;

[1] Edward Hill, My daughter Beatrice, *American Physical Society*, 1986 (see Book Review in this issue, p.84).

[2] Katherine Haramundanis (Editor), *Cecilia Payne-Gaposchkin*, Cambridge University Press, 2nd Edition, 1996 (with prefaces by the editor, Cecilia's daughter, and by V Trimble)

[3] Margaret Burbidge, Watcher of the skies, *Annual Reviews of Astronomy and Astrophysics*, Vol. 32, pp.1-36, 1994.

[4] http://www.ciw.edu/rubin