Journal and Proceedings of the Royal Society of New South Wales, vol. 144, nos. 3&4, pp. 83-90.
ISSN 0035-9173/11/020083-8

The accelerating universe

A new view of the universe

Ragbir Bhathal

School of Engineering, University of Western Sydney, Kingswood Campus, Penrith, NSW 1797

Email: r.bhathal@uws.edu.au

Abstract

Brian Schmidt was the leader of one of the two supernova search teams that discovered the universe is accelerating. His discovery was named Science Magazine's breakthrough of the year for 1998 and in 2011 he was awarded the Nobel Prize for Physics, along with Saul Perlmutter (University of California, Berkeley) and Adam Riess (John Hopkins University). He is a Fellow of the Australian Academy of Science and of the US National Academy of Sciences. He has made significant contributions in observational cosmology, supernovae, gamma ray bursts and all-sky surveys. This paper is based on an interview with him. It traces the trajectory that led Brian Schmidt to the accelerating universe and other achievements in astronomy.

Keywords: accelerating universe, dark energy, dark matter, Hubble constant, supernovae.

Introduction

From Missoula, Montana to Alaska, to Arizona, to Boston to Australia and the accelerating universe! Incredible as it sounds this is the long, arduous and exciting journey that Schmidt travelled over the first thirty-one years of his life. It was a life full of ups and downs. As a young boy he had already got a taste of moving from one place to another as his parents followed their careers and academic pursuits. So this movement from one place to another was inbuilt into his psyche. In some ways it was a traumatic experience for a growing lad but he seemed to have taken the changes in his stride as he made new friends and lost old ones and acclimatised himself to new places and environments.

Born in the small country town of Missoula, Montana in the Rockies in the northern part of the United States, he was very close to his young upwardly-mobile parents. As a young boy he acquired the protestant work ethic from his parents. From his father, a fisheries biologist he saw "the whole academic stream

and it quite appealed to me", he said. He also learnt the basic scientific skills of observation and experiment from him. "My mother", he said, "did a Master's degree in social sciences and I guess she showed me that there is a bunch of skills that she used in her jobs which are important as a scientist, which I think has made me a better scientist than I would have been otherwise". It is perhaps his mother's influence that has made him an excellent communicator of scientific ideas and an interesting and lively speaker for astronomy and science.

He did not attend posh private schools but spent his entire school life in government schools which in some cases had very good and highly motivated teachers. When he was fourteen his parents moved to Alaska. He attended Bartlett High School which according to Schmidt, "was a superb school. The teachers there were funded by Alaskan oil money and so

I had four teachers that had PhDs at high school and, you know, going to university was quite a step down and that's extremely unusual". He came under the influence of some very good science teachers who challenged him. But they were a little concerned that he wanted to do physics because many of their best students went out and failed physics. "And their view was that I wasn't the best they ever seen and I was going to fail. I think I probably surprised them how well I did".

From Arizona to Harvard

From Alaska he went to the University of Arizona in Tucson to do his undergraduate studies. Why to Arizona, when he could have gone to the University of Washington which was closer to home or the University of California? The University of California, he said, "was too expensive and hard to get into". He is not sure why he chose Arizona. "And to this day, I still ask myself, why did I go to the University of Arizona?" Although at the time he applied to study at the University of Arizona, he was not aware of the poor reputation of the Physics Department. However, he was aware that the astronomy department had a good reputation. After all Bart Bok (a former Director of the Mount Stromlo Observatory in Canberra) was an excellent representative of the astronomy department at that University. He spent most of his undergraduate years working long hours on his studies. "Spending almost sixty to seventy hours a week working on his studies", he said. Apart from the physics classes, he attended "a lot of astronomy classes and I had a good teacher there. Thomas Swihart". The academic staff were supportive and according to him, "they set me up to do a research project which I got embedded in with a guy by the name of John McGraw and interestingly enough, one of the things I got involved in doing was looking for supernovae". Some of the astronomers at the time he was there he recalls were Peter Strittmatter, Simon White, Rob Kennicutt, Dave Arnett, Craig Hogan, Jim Leibert, and Frank Low. Leibert was working on white dwarfs while Low was carrying out his well known studies in infrared astronomy.

On completing his undergraduate degree he had to decide where to go for his PhD studies. He could have gone to the University of California Santa Cruz where Sandy Faber, Mike Bolte, Stan Woosley, George Blumenthal, Peter Bodenheimer and David Koo were extremely active in studies that interested him but instead he chose to go Harvard University where Robert (Bob) Kirshner was actively engaged in research on supernovae. His decision to go to Harvard was made when he attended the first Marc Aaronson Memorial Lecture given by Kirshner at the University of Arizona. Marc Aaronson (a close collaborator of Jeremy Mould, a former Director of the Mount Stromlo Observatory and now of the National Optical Astronomy Observatory in Tucson) was killed in a freak telescope accident. According to Schmidt, he said to Kirshner, "I'll make you a deal. You let me be your student, allow me to work on supernovae and I'll come to Harvard because I have to make a decision. He replied, "Okay it sounds good". Once there he was not very keen on the supernova topics that Kirshner was suggesting. So he came up with his own idea for his PhD thesis. He informed Kirshner that he would like to measure the Hubble constant using supernovae, not just any supernovae but SN II. Unlike Supernovae Ia which are thermonuclear explosions in white dwarfs, type II supernovae result from the collapse of a massive star. When the outside of a SN II is ejected, it is still mostly hydrogen. The properties of the expanding, cooling atmosphere can be computed in detail and this was done by Ron Eastman, a postgraduate student in Kirshner's group (Eastman & Kirshner 1989). By repeated measurements of the temperature, speed, and brightness of the supernova atmosphere it is possible to figure out how large the atmosphere is and compute the distance to the explosion. Schmidt teamed up with Eastman who was "writing a very fancy computer code" which modelled what was happening in the supernova from a physical basis. "I worked with Ron Eastman and Bob very carefully to model these supernovae and that told us how many watts they put out so that we could therefore know how bright they appeared on Earth, compare that to how many watts intrinsically they were, and using the inverse square law, the fact that light gets fainter by distance squared, measure the distance directly to objects outside of the local universe". Using the expanding photosphere method he measured fourteen supernovae for his PhD thesis. This enabled him, "to measure a value of the Hubble constant which was independent of any other means and could be compared directly with cepheids and it turns out the value I got, 73 plus or minus eight kilometres per second per megaparsec" was very close to the now accepted value of about 72 km/s/Mpc (Schmidt B et al. (1994)). It is interesting to note that some of the galaxies with SN II data and expanding photosphere distances were also galaxies in Wendy Freedman's Key Project sample. The results agreed very well.

At the time he was doing his work on supernovae II there were two other groups who were also measuring the Hubble constant (H_0). There was controversy and acrimonious debate as to what was the real value. In the 1970s Gerard de Vaucouleurs then at the University of Texas and a past member of the academic staff of Mount Stromlo Observatory favoured a high value for H_0, of around 80 or 90 while Alan Sandage and Gustav Tammann strongly maintained that 50 was the correct answer. Sandage, a protégé of Hubble (Overbye (1991)) believed that he owned H_0 and anyone who did not accept this value was an idiot or a country bumpkin. The debate dragged on into the 1990s. According to Schmidt, "there was the Sandage, et al. group who were convinced it was 50. There was the Mould, et al group who thought it was 80 something but were not quite sure". Schmidt started out with a value of 60 but "then we re-did the models and made some improvements and it drifted to 73. So at 60 I was very popular with Alan Sandage. At 73 he called me a traitor. I think he has forgiven me".

Schmidt's PhD thesis was significant and it provided confirmation of the Key Project team's measurements of the Hubble constant with the Hubble Space Telescope of 72 kilometres per second per megaparsec. The key project work was mostly carried out by Jeremy Mould and Brad Gibson at Mount Stromlo Observatory. Other key players were Wendy Freedman at Carnegie and Rob Kennicutt at the University of Arizona (Freedman et al. (2001)). According to Schmidt the work he did on the Hubble constant "was a good grounding in what came later, the accelerating universe".

It was unusual to be given an internal job straight after a PhD at Harvard but that was exactly what happened in the case of Schmidt when he finished his PhD in 1993. According to Kirshner, "Although we usually liked to push the fledglings out of the nest, Brian was so extraordinary he won one of the competitive postdoc jobs at the Centre for Astrophysics. This gave him the chance to step out as an independent worker" (Kirshner 2002).

To Australia and the accelerating universe

On a visit to Harvard, Mario Hamuy from Chile not only showed Schmidt and his colleagues new supernova data but also showed them "very clearly you could use Type Ia supernovae to measure accurate distances". According to Schmidt, "In 1991, there was the idea that Type Ia supernovae were perfect standard candles. I was very sceptical about using Type Ia supernova for cosmology because we didn't know very much about them". In 1991 two unusual supernovae, SN 1991T and SN 1991bg were discovered. They strengthened the case that there were real differences among SN Ia and their discovery cast doubt as to whether SN Ia could be used as standard candles (Leibundgut et al. (1993)). Supernova 1991bg was intrinsically faint and appeared to be ten times fainter than an earlier SN Ia in the same galaxy. It rose and fell much more quickly. On the other hand SN 1991T was exactly the opposite, it was much brighter and it rose and fell more slowly. This intrigued Mark Phillips and by plotting the luminosity of several supernovae he found that the rate supernovae rise and fall is a very good indicator of how bright they are intrinsically (Phillips (1993)). According to Schmidt, "that was the relationship with a new, independent dataset that was shown to me in 1994. They found that Phillips' relationship made the supernova behave very nicely, you can measure distances to about eight per cent in accuracy which may not sound brilliant on Earth, but in astronomical terms when we are used to everything being about thirty per cent, that was good. Eight per cent was outstanding". Mario Hamuy had taken Phillips idea and turned it into a solution to the puzzling luminosity differences in the supernovae in a paper of which he was the first author (Hamuy et al. (1996)). In fact, he showed that Phillips was correct. The slow declining supernovae are the bright ones and the fast decliners are the faint ones. By measuring how fast a Type Ia supernova fades after it reaches maximum brightness, you were not likely to make any mistakes in assigning it the wrong distance. The scene was set for using Type Ia supernovae as distance indicators.

In the same month Schmidt had found out that Saul Perlmutter and his group at the University of California, Berkley had found seven distant objects to enable them to trace back the expansion history of the universe. They had begun a serious study of supernovae in the late 1980s with a combination of Rich Muller from the Physics Department and the Lawrence Berkeley Laboratory, including Carl Pennypacker (Filippenko et al. (2001)). Alex Filippenko from the Astronomy Department joined them sometime in 1994. Perlmutter, with a forceful personality joined them later and became the leader of the group although he was quite a junior academic. Schmidt's view was that "if those guys at Berkley can find supernovae, we sure as hell can. We had all the supernovae expertise, let's get out and do that". That was the genesis of the High-Z Supernova Team. It was formed at about the time Schmidt arrived in Australia at the Mount Stromlo Observatory. He was twenty-seven years old. It is rather remarkable that he was going to lead an international team to explore the past history and the future of the universe at that young age. He said, "I knew I wanted to go back and measure the past history of the universe, but this was going to require telescope time which I did not have access to in Australia". He worked out a strategy to unveil the secrets of the universe. "We needed the world's largest telescope, the Keck telescopes, we needed access to the Hubble Space Telescope. We needed a big whack of time on the wide field imager on the Cerro Tololo four metre. And so I went through and I took the people I knew in supernovae which was the Chileans, who helped determine the relationship that allows us to use them. Alex Filippenko from Perlmutter's group at Berkeley joined us in 1995 when the power of the Keck telescope became apparent. Filippenko had access to Keck. Chris Stubbs, who worked on the MACHO experiments here and was someone who was interested in large data sets was invited. Bob Kirshner, my supervisor for his general expertise and Bruno Leibundgut who had access to European facilities". They started with about fourteen people which eventually became twenty.

In 1995 they found their first supernova – called Supernova 1995 K which turned out to be an extremely interesting supernova. The supernova was 40% fainter than he had expected it. "This single object seemed to show that the universe is speeding up", he said. But to provide concrete evidence they needed more objects.

1998 was Schmidt's year. It began with publishing a number of papers which tackled the problem of the state of the universe, experimental techniques to study the universe and the equation of state of the universe (Garnavich et al. (1998a), Garnavich et al. (1998b), Riess (1998), Schmidt et al. (1998)). "At the end of 1997, Peter Garnavich had put together four new objects (five in total) now, and these showed that the universe was not slowing down quickly. It was a month later when Adam Riess (along with Schmidt and Garnavich – who were the three postdocs in the group) assembled fourteen objects that we saw the signal of acceleration", Schmidt informed me. So in 1998 they showed that the universe wasn't slowing down at all. Indeed, it seemed to be speeding up. According to Schmidt, "It was a big thing because here we have observations that the universe is speeding up. What does it mean? It means that the universe has to be full of an energy which pushes on the universe rather then pulling it. We were telling the world that seventy per cent of the universe is made up of a material that you did not know existed. That is, there is something out there ripping the universe apart which is the most fundamental thing in the universe and we never knew it existed. And we did this with the Perlmutter group who turned out had independently made the discovery. Our papers came out ahead of theirs. They hit the press release before we did. Anyway, the important thing is that the two groups were independent".

It was a remarkable discovery. It was all the more remarkable because although there was not much love lost between the two groups when they first began on this quest they ended up by agreeing that the universe is accelerating. The discovery was Science Magazine's discovery of the year for 1998. Einstein's blunder was not a blunder after all. One recalls that earlier in the 20th century Einstein had added a cosmological constant to his general theory of relativity to balance the motion of the universe so that it would be stationary. So, I asked Schmidt whether his accelerating universe confirms Einstein's theory? According to Schmidt, "In some sense it does. I'm not sure whether it confirms it but it certainly is pointing towards the cosmological constant. But it is hard to understand why the cosmological constant is so small and not zero".

Supernovae provide the only evidence for acceleration but when combined with the microwave background an interesting picture of the universe emerges. The measurements allowed the astronomers to pin down how much dark energy (Ω_λ) and how much dark matter (Ω_m) the universe contains. The supernova data gave a value of $\Omega_m - \Omega_\lambda$ and the cosmic microwave background (CMB) measurements gave a value of $\Omega_m + \Omega_\lambda$. So in their paper on the constraints in cosmological models the High-Z Supernova team crossed the data from supernova with that of the CMB (Garnavich et al. (1998b), Tonry et al. (2003)) and to their amazement found $\Omega_m = 0.3$ and $\Omega_\lambda = 0.7$. In effect, the results were telling the astronomers that in the early universe the density of matter in the universe was greater than now and at some point in time dark energy took over to give us an accelerating universe in which we live today. But the astronomers don't have a clue what the dark energy is that is accelerating the universe.

Has the problem of the cosmological parameters been completely solved or were there some other problems which needed to be resolved, I asked Schmidt. According to him, "I'm fairly heretical on this. And I believe we've done most of it. The theorists are aching to show that it isn't the cosmological constant. My view is we've shown that it's close to the cosmological constant. And I think we can probably improve things by a factor of three with $1 billion. That's where we are at. A billion dollars gives you a factor of three improvement in our measurement. And if the billion dollars do not show anything, that's a very expensive billion dollars for not a lot of gain. So that is where we are heading, measuring the equation of state. But it's not something that interests me. I'm doing it as a sideline, but I'm trying to shift my focus to other things because I think we have done most of what we can do and it's time to move on to other problems which are more interesting".

Skymapper

He is the team leader of the SkyMapper project (http://www.mso.anu.edu.au/skymapper) which will be constructing a comprehensive digital map of the southern sky. He said, "It will produce a petabyte of data. It will be used to find very rare objects and help us answer a whole range of different science issues". So what were the issues he was trying to solve. According to him, "There are a few intrinsically bright, but not too bright quasars that were formed at the dawn of the first stars. And there are three known right now from the northern hemisphere search which did not go as far as the SkyMapper will go and has not done as much sky area. And so, we should be able to take those three objects and make twelve or fifteen. And those objects will allow us to probe the universe and see how the universe turned on, and what age it did and the process behind it". The objects could also be used as places to undertake radio observations with the Murchison Widefield Array to look at the hydrogen before it was ionised – a project being worked on by a range of astronomers across Australia, and the US at MIT and Harvard. He hopes to feed objects for them to look at.

Another interesting thing he said, "we can do is to look at the first stars in our galaxy. We can actually pinpoint the stars that have almost nothing other than hydrogen and helium in them by their colours. And right now this university (i.e., the Australian National University) is leading this area of research".

The Oort Cloud which was first postulated by the Dutch astronomer Oort will also come under his scrutiny. It is the home of comets. "Paul Francis will be using the SkyMapper to find out what's going on in the Oort Cloud by seeing what is going on in the outer solar system with these comets as they come into our neighbourhood". He sees the SkyMapper as a great resource "not just for me, but for the entire astronomical community". As we roamed over a number of astronomical topics and drank several cups of coffee, I finally asked Schmidt what he considered was the major achievement in his life to date? "Certainly the accelerating universe is a level above everything else I have done and probably will ever do. It is my hope that SkyMapper will come close to the accelerating universe. It will not reach the novelty of the accelerating universe but my hope is it will be a major iconic piece of work at that level. The work we have done in gamma ray bursts has been good. The work on supernova physics and the Hubble constant was actually quite an influential piece of work". Perhaps, we will hear of more major discoveries with the SkyMapper in future years.

Conclusion

This paper has shown some aspects of the life and scientific achievements of one of Australia's foremost astronomers. It has revealed the steps that led to the discovery that the universe is accelerating and the amount of dark matter and dark energy the universe contains.

Acknowledgements

The author thanks Professor Brian Schmidt, Dr John Davids and an anonymous reviewer for reviewing and providing useful comments on the paper. The author also thanks the National Library of Australia for sponsoring the National Oral History Project on significant Australian Astronomers and Physicists. The interview with Professor Brian Schmidt was conducted in 2006 at the Mount Stromlo Observatory (now known as the Research School for Astronomy and Astrophysics) in Canberra. The full transcript of the interview is held in the Oral History Collections of the National Library of Australia.

References

Eastman, R. G. and Kirshner, R. P. (1989) Model atmospheres for SN 1987a and the distance to the Large Magellanic Cloud; *Astrophysical Journal*; **347,** 771-793.

Filippenko, A. V. (2001) Einstein's biggest blunder? High-redshift supernovae and the accelerating universe; *Publications of the Astronomical Society of the Pacific*; **113,** 1441-1448.

Freedman, W. L., Madore, B. F., Gibson, B. K., Ferrarese, L., Kelson, D. D., Sakai, S., Mould, J. R., Kennicutt, R. C. Jr., Ford, H. C., Graham, J. A., Huchra, J. P., Hughes, S. M. G., Illingworth, G. D., Macri, L. M. and Stetson, P. B. (2001) Final results from the Hubble Space Telescope Key Project to measure the Hubble Constant; *Astrophysical Journal*; **553,** 47-72.

Garnavich, P. M., Jha,S., Challis, P., Clocchiatti, A., Diercks, A., Filippenko, A. V., Gilliland, R. L., Hogan, C. J., Kirshner, R. P., Leibundgut, B., Phillips, M. M., Riess, D., Riess, A. G., Schmidt, B. P., Schommer, R. A., Smith, R. C., Spyromilio, J., Stubbs, C., Suntzeff, N. B., Tonry, J. and Carroll, S. M. (1998a) Supernova limits on the cosmic equation of state; *Astrophysical Journal*; **509,** 74-79.

Garnavich, P. M., Kirshner, R. P., Challis, P., Tonry, J.; Gilliland, R. L., Smith, R. C., Clocchiatti, A., Diercks, A., Filippenko, A. V., Hamuy, M.,Hogan, C. J.,Leibundgut,B., Phillips, M. M., Riess, A. G., Schmidt, B. P., Schommer, R. A., Spyromilio, J., Stubbs, C., Suntzeff, N. B. and Wells, L. (1998b) Constraints on the cosmological models from the Hubble Space Telescope observations of High-Z supernovae; *Astrophysical Journal Letters*; **493,** L53.

Hamuy, M., Phillips, M. M., Suntzeff, N. B., Schommer, R. A., Maza, J. and Aviles, R. (1996) The absolute luminosities of the Calan/Tololo Type IA supernovae; *Astronomical Journal*; **112**, 2391-2397.

http://www.mso.anu.edu.au/skymapper

Kirshner, R. P. (2002) *The extravagant universe*, Princeton University Press, Princeton, USA.

Leibundgut, B., Kirshner, R. P., Phillips, M. M., Wells, L. A., Suntzeff, N. B., Hamuy, M., Schommer, R. A., Walker, A. R., Gonzalez, L., Ugarte, P., Williams, R. E., Williger, G., Gomez, M., Marzke, R., Schmidt, B. P., Whitney, B., Coldwell, N., Peters, J., Chafee, F. H., Foltz, C. B., Rehner, D., Siciliano, L., Barnes, T. G., Cheng, K. P., Hintzen, P. M. N., Kim, Y. C., Maza, J., Parker, J. Wm., Porter, A. C., Schmidtke, P. C. and Sonneborn, G. (1993) SN1991bg – A new of Type IA supernova with a difference; *Astronomical Journal*; **105,** 301-313.

Overbye, D. (1991) *Lonely hearts of the cosmos*, Pan Books Limited, London, UK.

Phillips, M. M. (1993) The absolute magnitudes of Type IA supernovae; *Astrophysical Journal*; **413**, L105-108.

Riess A G (1998) Observational evidence from supernovae for an accelerating universe and a cosmological constant; *Astronomical Journal*; **116,** 1009-1038.

Schmidt, B. P., Kirshner, R. P., Eastman, R. G., Phillips, M. M., Suntzeff, N. B., Hamuy, M., Maza, J. and Aviles, R. (1994) The distances to five Type II supernovae using the expanding photosphere method, and the value of H_o; *Astrophysical Journal*; **432,** 42- 48.

Schmidt, B. P., Suntzeff, N. B., Phillips, M. M., Schommer, R. A., Clocchiatti, A., Kirshner, R. P., Garnavich, P., Challis, P., Leibundgut, B., Spyromilio, J.,Riess, A. G., Filippenko, A. V., Hamuy, M., Smith, R. C., Hogan, C., Stubbs, C., Diercks, A., Reiss, D., Gilliland, R., Tonry, J., Maza, J., Dressler, A., Walsh, J. and Ciardullo, R. (1998) The High-Z Supernova Search: Measuring cosmic deceleration and global curvature of the universe using Type 1A supernovae; *Astrophysical Journal*; **507,** 46-63.

Tonry, J. L., Schmidt, B. P., Barris, B., Candia, P., Challis, P., Clocchiatti, A., Coil, A. L., Filippenko, A. V., Garnavich, P., Hogan, C., Holland, S., Jha, S., Kirshner, R. P., Krisciunas, K., Leibundgut, B., Li, W., Matheson,T., Phillips, M. M., Riess, A. G., Schommer, R., Smith, R. C., Sollerman, J., Spyromilio, J., Stubbs, C. W. and Suntzeff, N. B. (2003) Cosmological results from High-Z supernovae; *Astrophysical Journal*; **594,** 1-24.

Ragbir Bhathal PhD

(Manuscript received 9 August 2011; accepted 26 October 2011.)

Dr Ragbir Bhathal was President of the Royal Society of NSW in 1984 and was awarded the Royal Society of NSW Medal in 1988. He has published several papers in international refereed journals and fifteen books, eight on astronomy.