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Galaxies and the HI Survey

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Abstract

Lister Staveley-Smith is a Premier's Fellow at the University of Western Australia. He was appointed by the Western Australian government to ensure that the Square Kilometre Array (SKA), the largest radio telescope in the world will be built in Western Australia. To this end the Western Australian government has so far contributed $30 million towards the $2 billion SKA project. Staveley-Smith was previously the Assistant Director Astrophysics at the Australia Telescope National Facility in Sydney. He is an expert in the study of galaxies and the Magellanic Clouds. He was the driving force in the building of the highly innovative Parkes 21 centimetre multibeam receiver which has made several significant contributions in astrophysics.

Keywords: HI survey, Multibeam receiver, Square Kilometer Array

INTRODUCTION

Out of Africa? Not exactly! But Lister Staveley-Smith spent a number of his younger years in Africa, an exotic continent of huge national parks, large rivers, great water falls and Mount Kilimanjaro made famous by Ernest Hemingway in his classic short story *The Snows of Kilimanjaro*. It was in Africa that the Leakeys and others found the remains of our ancestors who walked the length and breadth of the ancient continent thousands of years ago to finally emerge out of Africa with octopus like tentacles to spread themselves over the whole of planet Earth.

Born in Edinburgh in the Sputnik era Staveley-Smith was the only child of a mother who was a public servant and a father who was an English teacher with an avid interest of science. 'My father was a very outgoing person. Though he didn't in any way have a science background or an analytic brain, he had a fascination for science which must have rubbed on me when I was growing up.' In fact, despite his non-science background his father started 'an astronomy club in school.' As a young boy Staveley-Smith played with Meccano sets in an era when Meccano sets were the thing most young boys played with before the advent of home computers. According to him, 'he was very much mechanically minded although at one stage one of my professional ambitions was being a veterinary surgeon.'

He found the Edinburgh museum 'a fascinating place to go to and I must have visited the science museum once a month or so. It was free and there were lots of buttons to press.' His interest in astronomy began when he was about twelve years of age. 'I developed an interest in astronomy mainly through reading about things astronomical from the National Library in Edinburgh. I certainly remember being influenced by science and even science fiction writings of people like Isaac Asimov and I've been very impressed by Fred Hoyle's book, *Frontiers of Astronomy*.'

He spent most of his secondary school years in Nairobi, Kenya. Lenana High School was a selective high school and many of its graduates 'went on to become leaders in Kenyan society', according to him. He was very interested in physics. He had some very good teachers in mathematics and science and they were 'directly responsible for his becoming interested in these subjects.' It was at this school that he assisted in building a 12 inch reflector and from the 'point of view of research I do now, we also built a small corner reflector radio telescope.'

CAMBRIDGE AND JODRELL BANK

He went up to Trinity College in Cambridge on an Exhibition and was rather pleasantly surprised to find out that it was also the College that the great physicist, Isaac Newton had attended in the 17th century. He found Cambridge a little difficult to get used to in his first year but by his second and third years he grew to like it. He particularly enjoyed the experimental work at the Cavendish and remembers his 'tutorial sessions with Martin Rees', an accomplished English astronomer and a prolific writer of books and scholarly articles and other stimulating researchers. While at Cambridge Staveley-Smith was encouraged by his lecturers 'to pursue a research career.'

After graduating from Cambridge he moved on to do his PhD at Jodrell Bank under the supervision of Rod Davies, a former Australian who had gone to live in the UK. 'Davies', according to Staveley-Smith, 'had a broad range of interests from the study of the galaxy to the cosmic microwave background.' Staveley-Smith's PhD thesis was on mapping peculiar velocities in the local universe. His PhD thesis was more significant in what it did not find. At the time it was thought that 'nearby structures in the universe, supergalactic structures, clusters and superclusters were responsible for generating the gravitational forces that were accelerating our own Galaxy.' He could not reproduce the results found by other astronomers and he believes 'these accelerations are undoubtedly generated at further distances. And to this day it still remains unclear where the bulk of this acceleration comes from.' From Davies he picked up 'certain ways of dealing with research problems which are part of my research tools arsenal to this day', he continued. He spent the next few years on post-doctoral fellowships. In fact, during this time he developed 'a new acoustic optical spectrometer which provided order of magnitude more bandwidth than available with traditional devices. And it was actually very important in discovering an important hydroxyl maser in a very distant galaxy.'

TO AUSTRALIA AND THE ATNF

A UK Science and Engineering Research Council Bicentennial Fellowship to celebrate the Bicentenary of Australia enabled Staveley-Smith to move to Australia to join the Anglo-Australian Observatory (AAO) as an independent post-doctoral Fellow. It was an interesting time to be at the Anglo-Australian Observatory as new initiatives were being undertaken at that time. From there he moved on to the Australia Telescope National Facility (ATNF) as a post-doctoral fellowship before being offered a permanent job at the ATNF in 1995 and later being appointed as the Assistant Director and Head the Astrophysics Department. At the time he joined the ATNF it had a different research environment from the AAO. Construction of the Compact Array was sucking up the resources of the ATNF. There were budget overruns and there was not a lot of spare money for pure research. But, according to Staveley-Smith, 'That turned around as the Compact Array came on line and people could move from old style research with old style facilities to new more innovative research. New money was also injected at various stages through external contracts given to ATNF'. Under his leadership as the Head of Astrophysics the number of students in the mid-1990s increased from about a dozen to 'over 30 PhD students.' He is particularly proud 'of the people we've been able to bring into the ATNF.'

Staveley-Smith has a track record of producing papers with high citation rates. He has tackled a number of problems in the evolution and structure of galaxies and dwarf galaxies. He defined dwarf galaxies 'as galaxies that have a luminosity which is fainter than around one per cent of the luminosity of the Milky Way'. Dwarf galaxies are by far the most numerous objects in the extragalactic Universe. Some 80 per cent of the known Local Group galaxies are dwarfs, and the space density of dwarfs may be a couple of orders of magnitude higher than that of bright galaxies. He believes there are 'quite a few problems that relate to the formation of dwarf galaxies and their overall role in the formation process of galaxies. For example, do hydrogen rich dwarf galaxies become the dwarf elliptical galaxies that are known to surround the Milky Way in great numbers? Do blue compact dwarf galaxies evolve into low surface brightness galaxies and vice versa? How do dwarf irregular galaxies manage to sustain ongoing star formation over such long time scales? Many of these objects are still quietly forming stars, 14 billion years after the big bang.' Overall dwarf galaxies are very important in cosmology, however, they are still the poor cousins of normal galaxies according to Staveley-Smith.

In their study of HI and the optical observation of dwarf galaxies (Staveley-Smith, et al. 1992) they were 'able to derive a good estimate of the rotation velocities and if you base the size on the optical size of the galaxies it turns out you got quite a good estimate of the dark content without knowing exactly how far the hydrogen extended. But even the extent of the hydrogen is little indication of how far out the dark matter itself actually stretches'. Since his early studies of dwarf galaxies a number of studies have been done and are still being done, particularly 'in examining the role of dark matter in dwarf galaxies.'

In outback Australia the Large and Small Magellanic Clouds (LMC and SMC) can be seen as two fuzzy patches in the night sky. They are important satellite galaxies of the Milky Way. They are not quite the closest anymore as we now know of closer objects, such as the Sagittarius Dwarf Elliptical Galaxy. The LMC and the SMC are great laboratories for astronomers particularly because they lie well above the obscuring plane of our own galaxy. They are tremendous laboratories for the study of galaxies both on a global scale and on a very detailed scale for studying the interactions of individual star-forming regions with the interstellar medium and on a grand scale of things their interaction with each other and our own Galaxy. This interaction has not only been important for the past evolution but also the future evolution of the Milky Way and the Magellanic Clouds.

The survey of neutral hydrogen emission in the Small Magellanic Cloud with the Australia Telescope Compact Array (Staveley-Smith, et al. 1997) was an important milestone for Staveley-Smith. 'This was a particularly interesting study for me because it was of great astronomical importance of having the compact array available in the Southern Hemisphere. We did not have anything like the Very Large Array to study the SMC previously. The SMC has always been the poor brother of the LMC as far as attention by astronomers is concerned.' The study was also important to Staveley-Smith. 'It was a huge technical challenge in its time because of various telescope related and software related issues. And because I was at a national facility I felt it was my duty to pursue this and fortunately I was able to bring together a very competent team of people to pursue this. It was also significant because it was a stepping stone to the study of the LMC.'

They found that the spatial power spectrum relation (Stanimirovic, et al. 1999) followed a similar pattern as that found in our Galaxy by other astronomers. Their study emphasized to them 'that there was an input of energy into the SMC at many size scales, from the very large scale gravitational interaction with its neighbours, to the smaller spatial scale where winds from stars and the mechanical output from supernova was able to drive bubbles into the interstellar medium'. This it seemed to them to lead in the SMC to a hierarchy of structure which is 'more akin to turbulence than anything else'. In those days turbulence was not seen as being relevant by astronomers. The emphasis was on a static two-phase or three-phase interstellar medium in hydrostatic equilibrium. According to Staveley-Smith, 'These days turbulence is taken very much more seriously and astronomers have the computational tools to study star formation in turbulent environments and turbulence is regarded as an important star formation mechanism in itself.'

His work on an HI aperture synthesis mosaic of the LMC (Kim, et al. 1998) provided some rather surprising results. On a large scale they were surprised by the overall regularity of the LMC and neutral hydrogen. 'Especially', he said, 'when compared with the almost scruffy irregular appearance of the LMC in optical photographs. And also with the SMC we were surprised by the number of massive shells of gas which were present.' 'The shells', he said, 'tell of recent star formation.' 'And that recent star formation stretches from say about one million years to a hundred million years. They have given us a useful indicator of the average state of the LMC in the period which immediately follows the encounter with the SMC. That encounter probably occurred about 200 million years ago, so as well as the LMC having a direct effect on the formation structure and tearing apart of the SMC, vice-versa is true as well. That interaction had some effect on the LMC. We by no means understand that fully'.

According to Staveley-Smith, 'There are still raging arguments about the effect of various compression waves on the star formation in various parts of the LMC'.

MULTIBEAM AND THE ALL SKY HI SURVEY

Staveley-Smith was the driving force behind the building of the highly innovative Parkes 21 centimetre multibeam receiver (Staveley-Smith, et al. 1996) and the HIPASS survey which was one of the largest and deepest HI surveys undertaken in the southern sky. It was a blind survey of the whole sky south of Declination 25° in the velocity range -1200 km/s $<$ cz $<$ 127000 km/s. It was also a period when he began to write papers with a large number of astronomers. Because of the scale of the instrument there was a sharing of its development with astronomers from the UK. The reason for this according to Staveley-Smith was 'that they had skills that we didn't have with low noise amplifiers and we had skills that they didn't have.' He was also interested in surveys as a means of tackling fundamental problems."

He had initially talked about the multibeam project with Alan Wright at Parkes on several occasions. Later on Wright and Raymond Haynes 'dreamed up a multi-beam project for the small MOPRA telescope'. The MOPRA is a 22 metre dish close to the Anglo-Australian Telescope site. This telescope can be used either for stand-alone observations at millimetre wavelengths or as a component telescope of the Australia Telescope Long Baseline Array. But this was a non-starter because of the engineering and scientific limitations of the project. Staveley-Smith took over the role of project scientist from Haynes and 'following a nod from the engineering team and approved by Ron Ekers' (then Director of the ATNF), he changed it from a three by three array into a 13 beam double hexagon array. For its time the massive array was a great challenge and a great leap forward. The main reason for the change was according to Staveley-Smith, 'the availability of cheap correlators. A correlator is the back end spectrometer of the array. And an instrument like this required a correlator that was as powerful as the existing Compact Array correlator which was hugely expensive. And also the quality of a number of the engineering teams at ATNF, principally those led by Warwick Wilson, Mal Sinclair and Trevor Bird. And in such a multi-disciplinary team it was just possible to not only think about a project like this but to do it.'

The multibeam instrument had several advantages in comparison with other telescope systems worldwide. According to Staveley-Smith, 'The massive field of view of the multibeam and the more or less uncompromised sensitivity made it a very fast instrument and the fastest such instrument for the better half of the decade I believe. At the time many senior people in other institutes held the view that single pixel receivers and single feed receivers would always be better because they could always be optimized in some way. But I think those views were blown out of the water as soon as we made the first sky measurement with the multi-beam instrument at Parkes because we took an uncompromised attitude to the sensitivity and made sure nothing diminished its ability to do a sensitive HI survey at 21 centimetres'.

With this instrument astronomers were able to undertake qualitatively different science from what had been done before. 'It wasn't more of the same more quickly but it was different scales of problems. Not just looking at individual galaxies anymore but looking at the whole sky at depths which are really quite interesting', he said.

The All Sky HI Survey was a tremendous success. One of the early papers that made the headlines was the investigation of the tidal disruption of the Magellanic Clouds by the Milky Way (Putman, et al. 1998). They discovered a leading tidal arm of the Magellanic system.

According to Staveley-Smith, 'This was a fantastic indication that the tidal forces, not just ram pressure forces were responsible for shaping the overall Magellanic system. And that implies that our own Milky Way galaxy must possess a very extensive dark matter halo because that's the only way that such features can be produced in models.' The project also enabled them to make a number of advances in instrumental and imaging techniques (Barnes, et al. 2001). 'One of them', Staveley-Smith said, 'was the ability to handle interference in a robust way. We developed a procedure that was able to without much intervention to produce final images and final data cubes which were mainly free of the effect of radio frequency interference which at these frequencies is all pervasive from PCs, printers, aeroplanes, mobile phones, satellites, et cetera.'

The 'Mass Function' is in many ways similar to the luminosity function which is used in optical astronomy. In many ways it is more fundamental than the luminosity function because mass is in general a more fundamental quantity. It is also a more useful term from a cosmological perspective. In their study of 1000 brightest HIPASS galaxies (Zwaan, et al. 2003, Koribalski, et al. 2004) team members were able to provide the first accurate measurement of the Mass Function. According to him, 'Previous surveys were of a few dozen galaxies and really open to all sorts of wild interpretations. So this for the first time gave us accurate Mass Function over a reasonable range of HI masses and it enabled us to divide that Mass Function into different classes of galaxies and the different density of types of galaxies.' The large sample of galaxies also enabled them to give an accurate measurement of the cosmological mass density of neutral gas: $\Omega_{\rm HI} = (3.8 \pm 0.6) \times 10^{-4}\,{\rm h}_{75}^{-1}$. They found that low surface brightness galaxies contributed only 15% to this value which was consistent with previous findings.

SQUARE KILOMETRE ARRAY

In 2004 the Western Australian government appointed Staveley-Smith and Peter Quinn as Premier's Fellows at the University of Western Australia to ensure that the Square Kilometre Array (SKA), the world's largest radio telescope would be built in Western Australia. The Western Australian and the Australian governments are currently contributing \$30 million and \$118.5 million respectively to help meet some of the key technology and engineering development requirements of the \$2 billion international SKA project.

The SKA is an ambitious project and if all goes well it will be completed in about 2020. At the moment South Africa and Australia are in the running. As for the funding, Staveley-Smith, said, 'The expectation is that Europe might put about a third of the funding, North America might put a third of the funding and the rest of the world will put in a third of the funding. The partners currently are many European countries, USA, Australia, Canada, China, Argentina, India, New Zealand, South Africa and Russia.' The SKA will have 'a collecting area of some 300 times larger than that of the Parkes telescope and around 20 times larger than the largest array in existence today.' The candidate site is in the shire of Murchison in Western Australia at a station called Boolardy Station about 300 km by road from Geraldton in a very radio quiet area.

There are a number of science goals that astronomers hope to achieve with the SKA. According to Staveley-Smith, 'one of the main headline goals of the SKA when the concept was first mooted was the ability to make HI maps of large spiral galaxies at redshift three. So it's through the HI line that galaxies will be mapped at high redshifts and it's through the HI line that we will be mapping the structure of the universe in this epoch of re-ionization because it's the balance between neutral gas and the ionized gas that is a sign of this re-ionization.' They will also be imaging galaxies at high redshift, testing Einstein's theory of general relativity in extreme environments around pulsars and studying the evolution of magnetic fields in the universe.

Is he expecting any surprises? He said, 'It's a telescope that is designed to be a facility for many decades. And undoubtedly in that time there will be many surprises. I personally think we might have quite a few surprises in the so-called study of the transient universe. That is objects switching on and off which have been tremendously exciting at other wavelengths, such as in the gamma-ray bands in recent years.'

Of his major achievements to date, Staveley-Smith said, 'I have taken a lot of pride throughout my research career in helping others in their research achievements and helping students and post-docs achieve what they wanted. As well as my own achievements I take pride in the achievements of others I have been associated with'.

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For the latest developments on the SKA refer to `http://www.skatelescope.org`

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