JOURNAL AND PROCEEDINGS
OF THE

ROYAL SOCIETY
OF
NEW SOUTH WALES

Volume 141 Parts 3 and 4
(Nos 429–430)

2008

ISSN 0035-9173

PUBLISHED BY THE SOCIETY
BUILDING H47 UNIVERSITY OF SYDNEY, NSW 2006
Issued December 2008

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Acknowledgements The Royal Society of New South Wales gratefully thanks the NSW State Government for their financial suppport of this publication.

ISSN 0035-9173

Journal & Proceedings of the Royal Society of New South Wales, Vol. 141, p. 33–37, 2008
ISSN 0035-9173/08/020033–5 $4.00/1

Searching for ETI

RAGBIR BHATHAL

Abstract: The search for extraterrestrial intelligence is a scientific experiment which has been pursued for the last forty-five years. Over one hundred searches (ranging from one-off to sporadic and continuous) in both the microwave and optical regions of the electromagnetic spectrum have been carried out during this time. To date no ETI signals with the required signature have been discovered. This paper discusses some of the most significant searches and future directions in the search for extraterrestrial intelligence.

Keywords: ETI search strategies; ETI radio searches, Nanosecond pulses.

INTRODUCTION

The scientific search for extraterrestrial intelligence or SETI for short had its beginnings in the second half of the 20th century. In its early years the SETI program was plagued by questions of its validity as a scientific discipline. In fact, several members of the IAU Commission 51 were extremely critical of it. However, this has not stopped astronomers and astrobiologists from continuing the search for ETI in the electromagnetic spectrum.

GENESIS AND RADIO SEARCHES

The genesis of the modern SETI experiment was a seminal paper published by Cocconi and Morrison in 1959 (Cocconi and Morrison 1959) which suggested that radio telescopes should be used to look for signals at 1420 MHz (21 cm line) from seven sun-like stars within 15 light-years from the Sun. Within five years of the publication of this paper in the scientific press several lines of inquiry were established, viz: radio, optical, probes and biospheres. The emphasis placed on each of these methods was different.

The first radio search was conducted in 1960 by Drake in his now famous Project Ozma experiment (Drake 1961). The search failed to detect any signals from ETI civilisations

Four search strategies emerged (brief directed searches on available telescopes, piggyback searches which operated on telescopes being used for mainstream astronomy programs, dedicated searches and distributed searches by amateur SETI astronomers worldwide) after Drake's historic search. Both targeted and sky survey techniques have been used. The microwave searches have mainly been carried out on so called 'magic' frequencies (the 21 cm hydrogen line) with frequency resolutions varying from Megahertz to a few hundredths of a Hertz. The size of the radio telescopes has ranged from a few metres in diameter to the giant 305 metres instrument at Arecebo, the world's most sensitive and largest radio telescope.

About ten years after Project Ozma the first dedicated search in the USA for ETI signals was carried out under the direction of J. Kraus and R. Dixon at the University of Ohio. Although a number of candidate signals were detected during the course of the program, including the now famous Wow! signature, however, none of them were reconfirmed. The Ohio SETI group is now engaged in the design and construction of the Argus radio telescope. The Argus telescope which is designed to cover most of the sky at L-band consists of a planar array of mass produced omnidirectional antennas which are capable of 'seeing' in all directions of the sky at once. (Ellingsen et al. 2008).

The Harvard University group began their SETI searches with suitcase SETI which was later reconfigured as Project Sentinel in 1983. Suitcase SETI was a portable high-resolution spectrometer developed in 1978–82 and connected to the Arecibo radio telescope in March 1982. It was further developed into META (Megachannel Extraterrestrial Assay), META II and BETA. All these instruments were used to carry out all-sky surveys. The Harvard BETA instrument scanned the waterhole region with a 250 million channel receiver, each channel being 0.5 Hz wide. It used a 26 metre dish and scanned 68 per cent of the celestial sphere four times from October 1995 until March 1999 when the antenna's mounting broke in a windstorm. The telescope was dismantled in May 2007.

The negative results of the BETA search has allowed the Harvard group to set some limits on the prevalence of transmitting civilisations albeit with certain qualifications (Leigh and Horowitz 2000). None of the archived candidates had the characteristics of an extraterrestrial signal.

The SERENDIP (acronym for the Search for Extraterrestrial Radio Emissions from Nearby Developed Intelligent Populations) program has its home at the University of California and began operations in the 1970s. It was designed for use in piggy back mode. This was to get around the difficulty of not being able to get telescope time on major radio telescopes. The SERENDIP equipment at the University of California has undergone a number of evolutions, viz: SERENDIP I, SERENDIP II, SERENDIP III, SERENDIP IV and SERENDIP V. Each stage in the evolution has been more complex and sensitive than the previous one. The number of channels has increased at each stage of its development. SERENDIP IV was designed and run by Werthimer, et al. (1997) in piggyback mode as an all-sky survey on the Arecibo telescope. The survey used a 168 million channel FFT spectrum analyser to search for narrow band radio signals in a 100 MHz band centred at the 21 cm hydrogen line. The system had a 1.7 second integration time, 0.6 Hz resolution and a sensitivity of 10^{-24} W/m^2. The latest SERENDIP V is much more sensitive and it can listen to 300 MHz of radio channels at once instead of 100 MHz. It piggy-backs on the Arecibo telescope and takes advantage of its 7-beam focal plane array. It uses coincident detections to discriminate against interference.

Project Phoenix is the flagship of the SETI Institute in California. It was the largest, most sensitive targeted search program. Project Phoenix's first major search program was carried out at the Parkes radio telescope in Australia from 2nd February to 6th June 1995 (Tarter 1997). The Parkes and Mopra antennas were used as a pseudo-interferometer to search for ETI signals from 209 solar-type stars in the Southern Hemisphere over the frequency range 1,200 to 3,000 MHz. The sensitivity of the observations was sufficient to rule out any narrow band transmitters stronger than 5×10^{12} Watts broadcasting during their observations.

Although no ETI signals were found the strategy of using two widely separated antennas linked together as a pseudo-interferometer proved to be an extremely effective way to discriminate against RFI.

After the Parkes survey, Project Phoenix used the Arecibo telescope to search for ETI signals from a list of 1000 promising stars within 200 light years of the Sun. The Arecibo telescope was paired with the Jodrell Bank telescope in the UK. The search frequency spanned the range 1,200 to 3,000 MHz and surveyed about 500 nearby stars. It concluded its nine year search in 2004. Project Phoenix has been replaced by a new program based on the Allen Telescope Array (ATA). It will use 350 mass-produced small dishes (6 m in diameter) to form a collecting area of 10,000 square metres and target 100,000 candidate stars for intensive SETI observations (Tarter 2001). In October 2007 the first 42 dishes began science observations.

Still in the planning stages is the development of the multinational Square Kilometre Array (SKA) which will be used for mainstream astronomical research and also for the cradle of life program which will have the SETI search as one of its components (Tingay 2008, Bhathal 2005). The main scientific thrust of the array is to study the structure of the early universe prior to the formation of galaxies with the use of highly red-shifted HI. It will also have the ability to synthesize up to 100 pencil beams simultaneously. Even if just ten beams were used for the SETI program it will be able to cover a million stars in a targeted search over a period of about ten years.

OPTICAL SETI

A quick calculation shows that the apparent magnitudes of the ETI star and the ETI CW laser at a distance of 10 light years from us would be 2 and 21. The laser source would just be picked up by the 200 inch telescope at Mt Palomar Observatory. However, it must be pointed out that in this scenario the host star would swamp the light from the laser. For the experiment to work we need to have more powerful lasers. Pulsed solid-state lasers have achieved terawatts, albeit for a few nanoseconds. The National Ignition Facility at the Lawrence Livermore National Laboratory could deliver 500 TW pulses lasting 3 to 5 ns.

These developments in laser power have opened the way for a consideration of the optical SETI search strategy as a viable search strategy (Bhathal 2000). However, the breakthrough came with the discovery a few years back of a long forgotten paper by Monte Ross who had been working on laser communications for the Research and Development Department at Hallicrafters Co., Chicago. In his now classic 1965 paper (Ross 1965), he noted that information theory shows that at optical frequencies, narrow pulse, low-duty cycle systems can convey more information per received signal photon than radio waves. Calculations show that a pulsed laser beacon will outshine its host star by four to seven orders of magnitude depending on the output of the laser. For example, for a pulsed laser beacon system with a 1 Hz repetition rate and a peak power of 10^{18} W it can be shown that the magnitude of the ETI laser and the ETI star at a distance of 10 light years would be -15 and 2. Sources of these magnitudes can be easily picked up even by small telescopes.

Over the last seven years four new optical SETI projects have come on line, viz: the University of California's SEVENDIP (acronym for Search for Extraterrestrial Visible Emissions from Nearby Developed Populations) project, the Harvard University optical SETI project, the Lick Observatory optical SETI project and the University of Western Sydney's Australian Optical SETI (or OZ OSETI for short) project. All projects are based either on very fast photomultiplier tubes or avalanche photodiodes. The equipment uses a beam splitter to feed the light from the telescope onto a pair of very fast photomultiplier tubes or avalanche photodiodes. The signals are fed to a pair of high speed amplifiers, a pair of fast discriminators and a coincidence detector. All are searching for nanosecond pulses with specially built coincidence circuits to eliminate false signals and noise which can be attributed to scintillation in the photomultiplier glass from cosmic rays, ion feedback and radioactive decay of potassium (K40) located in the PMT glass. Background noise and interference from astrophysical phenomena and atmospheric and terrestrial sources have been found to be negligible in the optical SETI experiments conducted to date. Most of the interference has come from detector pathologies. In general, this has been eliminated by the use of two or three detector systems with coincident circuits or two telescopes with detectors wired up in coincident mode.

The University of California is searching in the 300–650 nm wavelength range with a 0.8 m automated telescope at Leuschner Observatory. Fast PMTs with a rise time of 0.7 ns are wired up in coincident mode. They are searching for signals from F, G, K and M stars, a few globular clusters and galaxies (Werthimer et al. 2001). The pulse search has examined about 700 stars with a dwell time of about two minutes a star. The experiment's sensitivity is 1.5E-17 W/m^2 for a one nanosecond pulse. To date they have found no ETI signals.

The Harvard University project was searching in the 160–850 nm wavelength range but centred on 420 nm. They were also targeting F, G, and K stars. Their detector system rode in piggyback mode on a radial velocity survey. They synchronized their observations with a group at Princeton University located about 200 km away with the use of GPS receivers to synchronize the detection of pulses within a microsecond over the millisecond delay between the two observatories. By 2004 they had made observations of over 6,000 stars but they did not find any ETI signals of the nanosecond pulsed variety (Howard, et al. 2004). The Harvard group has built a 1.8 m dedicated wide-field optical telescope with a fast pixelated photodetector for an all-sky survey. The telescope is essentially used as a photon bucket.

The Lick Observatory project uses a three detector system which has been designed to eliminate the incidence of false positive signals that have been observed on the University of California and Harvard University two detector optical SETI systems. The system uses fast PMTs with a spectral response from 300-850 nm. The device is mounted at the f/17 Cassegrain focus of the Lick Observatory's 1 m Nickel telescope.

The OZ OSETI project was built mainly with private sector funding. It is searching for signals from transmitters with peak instantaneous power greater than 10^{18} W. The search is conducted in the 300–700 nm range but centred on 550 nm. The equipment is wired up in coincidence mode to eliminate false signals. The OZ OSETI project is the only dedicated optical search in the Southern Hemisphere. To date 2,000 stars and 30 globular clusters have been searched for ETI signals. A FFT analysis of all the observations with MATLAB has provided negative results to date.

THE FUTURE

Over the last few years a number of strategies have not only been revisited and refined but new search strategies have been developed. All of them are in various stages of development.

Major developments in detector technology could enable pulsed IR searches. From the point of view of the transmitter, pulsed infrared SETI has a number of advantages, such as, greater signaling range, lower energy cost per photon and decreased stellar background. This search strategy will become feasible when affordable fast detectors become available.

Ross and Kingsley (2001) are planning the PhotonStar project which will be an optical version of the SETI@home project but with a difference. The project is aimed at 'amateur' optical astronomers who already posses a well equipped observatory. GPS technology will be used to obtain precise location and time information for the observatories located across the USA. Each observatory will have a turnkey detector module and the data from each observatory will be collected and integrated over the internet.

The OZ OSETI project is planning to build a dedicated one metre optical telescope to be financed mainly by the private sector. The initial design plans have been drawn up. The telescope will be used as a light bucket in transit mode and will be able to complete a survey of the southern sky in about 250 nights. The detector will be based on Hamamatsu's recently released multi-pixel photomultiplier tubes which have a quantum efficiency between 10 and 20% for 300–550 nm, a gain of 10^6 and a rise time of about 1 ns and FWHM of about 3 ns.

Over the next few decades a number of space telescopes will be launched by ESA and NASA. The space telescope programs offer a tremendous opportunity of carrying out an optical SETI search along with other astronomical programs. The Terrestrial Planet Finder is planned for launch in 2015. It will look for traces of early life in the infrared spectra of extrasolar planets. As currently envisioned it will also be sensitive to deliberate laser transmissions from technologically advanced civilisations. A kilowatt class laser with a 10 m beam director would produce a signal visible to TPF at a range of 15 pc that is distinguishable from astrophysical phenomena and noise (Howard and Horowitz 2001).

Far into the future is a proposal for a SETISAIL project proposed by Jean Heidmann and Claudio Maccone (1994). They based their arguments on the gravitational lens effect of the Sun, solar sail technology and the galactic belt of advanced life to launch an inflatable combined sail/radio telescope system at a 550 AU distance outside the solar system. The sail would be focused at Balaz's maximum where it will go through a 7000 light years long section of the belt of life. They even propose a launch direction at galactic longitude of 270 degrees and galactic latitude of 0 degrees. Because of rising radio interference it is envisaged that sensitive SETI observations will be difficult to be conducted from Earth within the next ten to twenty years. Thus, Heidmann (2000) has proposed the establishment of an observatory on the far side of the Moon. He has suggested that the observatory be located at the Saha crater because no Earth or geostationary orbit based radio emission can reach this site.

CONCLUSION

For SETI to succeed it is imperative the search strategies be broad and varied. The reason for this is that no one really knows what type of communicating device ETI civilisations will use to contact us. Although forty-five years of searching have been conducted it would appear that we have barely begun the search.

ACKNOWLEDGEMENTS

The author wishes to thank Stuart Kingsely and Monte Ross for helpful and stimulating discussions on the search for ETI.

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(Manuscript received 08.2008, accepted 09.2008)

Journal & Proceedings of the Royal Society of New South Wales, Vol. 141, p. 39–43, 2008
ISSN 0035-9173/08/020039–5 $4.00/1

Antarctic Astronomy

RAGBIR BHATHAL

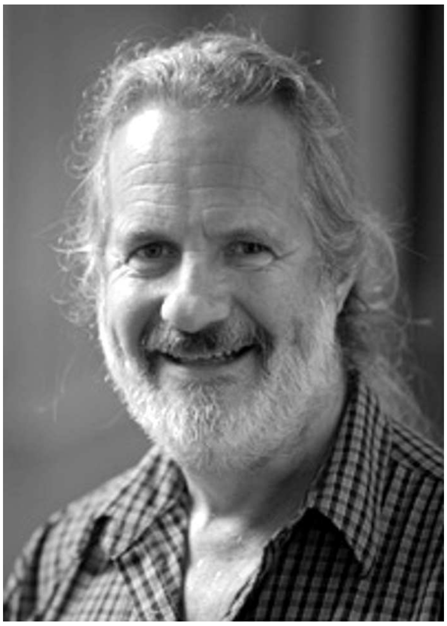
Abstract: John Storey is a Professor of Physics at the University of New South Wales. He was awarded the Pawsey Medal by the Australian Academy of Science and the Antarctic Service Medal of the US Congress. His research interests include Antarctic astronomy, infrared astronomy and millimetre wave astronomy and energy-efficient vehicles. He is Chairman of the Antarctic Astronomy and Astrophysics Expert Group of SCAR which helps to coordinate international astronomical research in Antarctica.

Keywords: Bio-astronomy, Infrared astronomy, Large telescopes

INTRODUCTION

John Storey's parents were both school teachers and as a result of that profession they moved around various towns during his early childhood. 'So we never spent more than a few years in any one place.' He had a varied and interesting childhood and perhaps because his parents moved from one place to another he did not have a large number of friends. So he spent a lot of his childhood in building things and playing with mechanical and electrical things. At about the age of ten he was given an OC71 germanium transistor which he built into his first crystal set. He remembers he said, 'listening to my one-transistor radio and hearing the announcement that President Kennedy had been shot. I went and told my parents who were shocked by the news.' That hobby evolved into amateur radio and at the age of fifteen he obtained an amateur radio license but was not able to legally operate a transmitter until he turned sixteen. These early experiments with things scientific and technical sparked in him a desire to be a scientist and later in life it showed up in his interest in building scientific equipment. It is rather surprising that his interest in astronomy came much later.

He was always near the top of his class and won a scholarship to study at Melbourne Grammar School. 'I was very lucky to have outstanding teachers in physics and chemistry. I also fondly remember the history and language teachers and I always enjoyed languages and history as much as I enjoyed science.' His father was 'probably the main person who motivated him into a physics-type discipline.'



LA TROBE AND THE UNIVERSITY OF CALIFORNIA

For his undergraduate studies he went to La Trobe University which happened to be close to his home. It was the time of the Vietnam War and like many socially conscious students he got 'into student politics and anti-war demonstrations.' At La Trobe he came under the influence of Keith Cole a well known ionospheric physicist and a great advocate of space science in Australia. From Cole he learnt 'that we should never worry about getting a job. That what we should do is what we were interested in.' 'I think it was very good advice', he told me.

After completing his Honours degree he joined the Chemistry Department at Monash University rather than the Physics Department to do his PhD under the supervision of Ronald Brown, an internationally recognized astrochemist. 'I saw this as an opportunity to do laboratory spectroscopy at microwave frequencies of molecules that had just been detected, or additional molecules that might be detected in interstellar space.' His PhD topic was on microwave spectroscopy and radio astronomy of biologically interesting molecules. 'For many years people believed that molecules could not exist in interstellar space because of the ultra-violet radiation field. I think the OH radical had been known since World War II from optical observations but it was not until 1968 that Charles Townes and Al Cheung discovered ammonia that it was realized that quite complicated molecules could exist. In the years immediately after 1968 I guess a dozen or more molecules were detected at radio telescopes including Parkes.' In searching for biological molecules he succeeded in 'getting a microwave spectrum of urea.' According to him, 'our ability to measure the microwave spectrum of urea was something of a breakthrough because that was the first biological molecule for which a microwave spectrum had been achieved.'

He went to Kitt Peak with Brown and Peter Godfrey to search for glycine with the 36 foot diameter radio telescope. While there 'we were able to look for the carbon 13 line of HNC and the fact that we were able to detect this meant that the identification of HNC was then assured (Brown, et al., 1976)'. The search for glycine was not successful (Brown, et al., 1979). In fact, over the years several astronomers have been trying to search for glycine in space but to date have not been able to detect it. Storey believes that 'there are tantalizing indications that glycine is there. I think it will eventually be detected. It is a surprisingly difficult molecule to find and in fact if you calculate how abundant you think it should be, just on the basis of how many atoms it has, at that abundance level it is extremely hard to find. The problem with it is that it is a completely asymmetric molecule.' There is much interest in the search for biomolecules in space because some astronomers and astrobiologists believe that life on Earth may have been seeded by biomolecules from outer space rather than having to start from scratch in Darwin's small warm pond on Earth.

For his post-doctoral fellowship he went to the University of California at Berkeley in the late 1970s and joined Charles Townes' group. Townes was a Nobel prize winner and the inventor of the laser. According to Storey, 'Townes was an absolute delight to work with. He was very much a renaissance man, interested in not just physics but also philosophy, religion, history and languages. He was extraordinarily kind and generous and very much engaged with his students. Townes was a great inspiration to me.' Storey spent four and a half years at Berkeley.

He said his time at Berkeley was one of his most creative periods. He was involved in 'developments there of infrared interferometry, and airborne astronomy on the Kuiper Airborne Observatory (KAO).' The interferometer had been built by Townes and his students Michael Johnson, Al Betz and Ed Sutton. With the 'two-telescope interferometer they were able to look at objects with much greater spatial resolution than had been possible before. But the main result at that time was looking at dust shells around stars. We were able to measure the diameter of those dust shells and measure the inner radius of that dust shell (Sutton, et al., 1977)'. He developed his own spectrometer (Storey, et al., 1981), a Fabry-Perot scanning spectrometer with a helium cooled detector and this 'flew on about eighty flights with the KAO.' They were able to detect molecules and characterize the warm gas component of interstellar gas clouds. They were also able to detect fine structure lines of various ionic species like [OI], [OIII] and [NIII]. When he returned to Australia he tried to arrange regular flights for the KAO in Australia. He succeeded in getting it once to Sydney at the Richmond Air Force Base. Due to some administrative and financial problems with the Richmond Air Force Base the KAO subsequently went instead to New Zealand and 'flew out of Christchurch.' KAO ceased flying in the late nineteen-eighties to make way for SOFIA and an Australian woman astronomer Jackie Davidson is one of its leading lights. SOFIA will be a tremendously powerful probe of the far infrared universe.

He wrote a review on infrared astronomical spectrometers which was a summary of the major developments in the field (Storey, 1985). ‘It was a very exciting in around 1985 because we were opening up this new spectral region. And part of the debate at the time and in fact is still ongoing is that at radio wavelengths it’s very clear what techniques to use. You use heterodyne techniques where you mix the incoming signal with a local oscillator and as soon as possible convert the signal into an electrical signal you can then process digitally. At optical wavelengths again it is clear you use a grating spectrometer or a Fabry-Perot spectrometer and do all the processing optically. And at the very last part of the instrument is the detector where you turn it into an electrical signal.’ ‘So it’s two completely different approaches,’ he said. ‘Now clearly these two techniques meet in the middle and they meet in the far infrared. And it’s in the far infrared that you really have to understand what the benefits are of using one technique or the other.’ The technology has changed very rapidly and according to Storey, ‘we are getting very close to the quantum limits of detection across the entire electromagnetic spectrum from low frequencies to X-rays. And so there is no longer really any debate. You simply look at what it is that you are trying to measure and it becomes very clear whether you use an optical technique or a radio type technique.’ In the far infrared both techniques have their place and he believes that the Herschel satellite will carry some radio-type heterodyne instruments and also some optical-type direct detectors.

UNIVERSITY OF NEW SOUTH WALES

He returned to Australia in 1981 and joined the Anglo-Australian Observatory which at that time ‘had been going for five or six years and was riding the crest of a wave as one of the most productive of the new generation of four-metre telescopes’ under the directorship of Donald Morton. He came back to a five-year position at the Anglo-Australian Observatory but a year later he joined the Physics Department at the University of New South Wales as a lecturer because they ‘offered him a permanent job.’ Five years later he was appointed to a new position as Professor of Physics. He was thirty-six and probably one of a very few academics in Australia to get a professorship at that age. Most Australian academics get a professorship in their late forties or fifties.

At the time he joined the School of Physics he said, ‘it was a lumbering kind of school. I think there were forty-two academics, most of them approaching retirement age so there were a lot of resources available.’ With Louise Turtle and colleagues he built the Astronomy Department which he said, ‘became the second highest cited Astronomy Department in the country.’ Turtle was also responsible for nominating him for the Pawsey Medal.

He was involved in the acquisition of a satellite-tracking optical telescope from NASA when NASA closed down their satellite tracking station at Orroral Valley. With Jack Cochrane, Louise Turtle and Peter Mitchell he heavily modified it for use as an astronomical facility and relocated it to Siding Spring to become the Automated Patrol Telescope. ‘It is now being operated by Michael Ashley and used for searching for extra-solar planets, gamma ray burst sources and for all kinds of transient sources. It is now a very successful and very productive facility and they are churning out several papers a year’, he said. With Michael Burton he was instrumental in fitting out the Mopra radio telescope with millimetre-quality panels over the entire surface. ‘So we basically turned Mopra into a millimetre telescope and then using ARC LIEF funding we are providing a very wide bandwidth receiver for the back end.’ Millimetre wave astronomy is a rapidly growing field. At the moment Mopra is the only big millimetre wave telescope in the southern hemisphere but that window of opportunity will be lost when ALMA (Atacama Large Millimetre Array) comes on line in South America.

ANTARCTIC ASTRONOMY

His major interest now is in Antarctic astronomy (Aitken, et al., 1994; Burton, et al., 2004). According to him, 'Antarctica offers several advantages. One is of course it's very cold and it's very high on the Antarctic plateau. Because the atmosphere is very dry you have got much better atmospheric transparency. In addition of course the infrared background is very much lower because it's colder and the skies are effectively twenty to fifty times darker across the infrared and so at infrared wavelengths you get a sensitivity gain of up to seven or ten. In addition to that the atmosphere's also extremely stable and so the image quality is much better than you get at any other site.' He believes that the high plateau sites are by far and away the best Earth-based sites for a lot of infrared and optical astronomy as well as submillimetre and millimetre wave astronomy. The other advantages, he said, 'of constructing there are the very low wind speeds and lack of earthquakes. So potentially you can build extremely large telescopes there, probably cheaper than they could be built at other sites.'

His ultimate ambition would be to build a 25 metre extremely large telescope. He has written a paper with Roger Angel from Arizona. But to get to that stage they are planning to firstly build a 2.4 metre optical infrared telescope. Called PILOT, he said, 'we would like to get on with that straight away (Burton, et al., 2005)'. The cost is about ten million dollars. The reason for building this first is to demonstrate that there are no insurmountable problems. The next stage after that is to build an eight metre telescope. He has in mind a proposal called 'LAPCAT' for that. The final step is to build the 25 metre telescope which would effectively be derived from the Giant Magellan Telescope.

They have done enough site testing at the moment to show that 'one can sensibly talk about building a big telescope. Furthermore the site conditions are so favourable that it is worth building a big telescope.' They have also done a great deal of technology development so that they know how to make things work in Antarctic conditions. They have, he said, 'built a robotic observatory that's worked for months with nobody around in Antarctica under the harshest conditions (Ashley, et al., 2004). We know how to do it and it is just a question of putting the pieces together.'

ACHIEVEMENTS

He has supervised about a dozen postgraduate students who have gone in different directions. Some of these are Kate Brooks who is now at the CSIRO Australia Telescope National Facility, Tony Travouillon is at Caltech while Paolo Calisse is at Cardiff University.

He has a very active research profile. He attributes this to Townes' influence which is 'not to do what is necessarily the obvious thing to do. That if it's clear what the next step is going to be in some field then why not let someone else do that because if it really is obvious then other people are going to come along and do it. So what's the point of you going in there and competing with them. It's much better to do something which otherwise wouldn't happen and to try and be creative and actually make a difference to the way science develops. So I guess throughout my career I've tried to do things that will actually make a difference rather than doing things that are perhaps easy.'

As to his achievements to date he said, 'I think putting UNSW physics and astronomy on the map. I think the other achievement of effectively launching the field of bio-astronomy has been something I can take some pride in although clearly I was only a PhD student at the time and so most of the credit should go to my supervisors. Opening up the far infrared spectroscopy through the work I did at Berkeley. But I would say that Antarctica would have to be the most important thing I've done. I thank the group here and it's been very much of a team effort with Michael Ashley and Michael Burton. Peter Gillingham at the Anglo-Australian Observatory I think should take a lot of the credit for stimulating the work that we've done and contributing to it. What we have shown is that Antarctica does offer enormous advantages for optical/IR astronomy and for other fields as well. And I think we've shown that this is an opportunity for Australia and I think if Australia does take the opportunity up then that will be the thing that saves optical/IR astronomy in Australia.'

ACKNOWLEDGEMENTS

The author wishes to thank the National Library of Australia for sponsoring the National Oral History Project on significant Australian astronomers. The interview with John Storey was conducted on 6 June 2006. The full transcript of the interview (nla.oh-5665) is held in the archives of the National Library of Australia (Storey & Bhathal 2006).

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(Manuscript received 08.2008, accepted 09.2008)

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Vol. 141 Parts 3 and 4

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DATE OF PUBLICATION December 2008