# 1.1 Discovery

The discovery of pulsars is one story in a line of serendipitous discoveries made at radio frequencies in the development of radio astronomy. Others include (see *Serendipitous Discoveries in Radio Astronomy*, Eds Kellermann, K. and Sheets, B., NRAO publications, 1983) non-thermal radio emission from the Galaxy, radio emission from the sun, solar radio bursts and the hot solar corona, non-thermal radio bursts from Jupiter, discrete extragalactic radio sources powered by synchrotron emission, quasars, and the Cosmic Microwave Background. In 1967 a large radio telescope at Lords Bridge near Cambridge, UK, came into operation. It was built primarily by student labour with materials provided by a grant of about 15,000 from the Science Research Council. The telescope operated at the low frequency of 81.5 MHz; its reflector was of loosely-strung wires attached to wooden posts covered 4.5 acres; and it was built to study the rapid variability of compact radio sources which by then had been found to scintillate due to irregularities in the solar wind streaming from the sun. Note the general purpose of the telescope - it would detect any object emitting sufficiently at 81.5 MHz and varying on a time scale (set by the output time constant of the final stage of the receiver - a pen recorder) greater than 0.1 second.

So - discovering pulsars:

**1. Observe**

Could pulsars help it if this telescope was perfectly designed to detect them? It was designed with a particular kind of radio source in mind, namely a point source that fluctuated. But it could detect any type of fluctuating source. The difference with pulsars is that they pulsed essentially on and off (as we now know, with the beamed cone of emission from the rotating neutron star sweeping through the beam of the telescope); whereas the extragalactic compact source for which the telescope was designed has a continuum modulated by blobby and rapidly-flowing ion screen of the solar wind. The key to discovery of pulsars was that this telescope was designed as a survey instrument, to detect as many new compact and scintillating extragalactic sources as possible. It was a transit instrument, surveying the sky by using four beams at a time at different declinations, these beams being shifted in declination each day by rephasing the interferometer. It was able to survey a large proportion of the northern sky in a few weeks of operation, and it did so in October and November of 1967.

**2. Reduce**

With the instrument in operation, a first task for the Tony Hewish's research student in charge, Jocelyn Bell-Burnell, was to sort out what was interference and what was real. The miles of chart record were analyzed by (her) hand and (her) eye. She noticed a recurrent form of apparent interference (it didn't show the characteristics expected of continuum), to which she gave the technical term 'scruff'. Despite the miles of records, she noticed that scruff appeared at only a few declination settings and at roughly the same time. She then discovered that it was not the solar time which was the same, but the sidereal, advancing in solar time by 4 minutes a day. The scruff generators were thus at fixed right ascensions and declinations, and unlikely therefore to be generated on earth. Finally, the interferometer team caught some of the scruff with a low-time-constant recorder, spread out the time axis, and saw the true (but intensity varying) pulses of pulsar CP1919.

### 3. Analyse

So what was it? Not instrumental; it was observed with a second Cambridge telescope for confirmation. Not local; these objects were fixed in the sky. But was it signals from extraterrestrial civilizations? Indeed the first pulsars discovered had 'scruff records labelled LGM1, 2, 3 for Little Green Men. The possibility was mentioned in the Nature discovery paper, with the consequent media hype - but it was unlikely from the start that widely separated stellar systems would chose the same frequency and method for communication. That they were relatively local systems had been indicated by dispersion measures presented in the discovery paper which suggested that the systems were at distances of 10s of parsecs.

### 4. Conclude

Fred Hoyle had suggested at Tony Hewish's announcement colloquium in Cambridge, just before the Nature paper appeared, that these were the remnants of supernova explosions. So it proved, out of the welter of competing theories – these were neutron stars, spinning faster than tops.

### 5. Reflect

Probably as a consequence of the bad feelings generated by the source-count controversy, it was claimed that the Radio Astronomy Group at Cambridge had kept the pulsar discovery a dark secret for far too long. In retrospect this is a ludicrous claim. The telescope became fully operational November 1967. The paper was submitted to Nature in early February 1968. With the analysis of miles of chart record, the attendant confirmations with other Cambridge telescopes and other instrumentation, the examination of all possible sources of interference, and the astrophysical considerations - this seems a remarkable achievement. Many members of the Radio Astronomy Group at Cambridge remembered Christmas 1967 as a non-holiday season.

If the 1967 telescope had been a 'modern one with ability to point to a second of arc, it might well have been used to measure scintillation of sources of known position as previously catalogued. No survey would have been done. Moreover if the records had been analyzed by computer alone, it is likely that scruff would have been rejected as interference or an instrumental effect. The discovery came about through instrumental development and sky surveys; and it came about because Jocelyn Bell-Burnells brain remembered (her words) – separated by the analysis of hundreds of feet of chart record –

that it had seen similar lots of scruff at similar times and declinations. The discovery of pulsars won Tony Hewish the Physics Nobel prize of 1974 (jointly with Martin Ryle for the invention of earth-rotation aperture-synthesis interferometry). This was the first Nobel prize ever awarded to astronomers. Discovery of the first double pulsar and subsequent verification of several aspects of General Relativity won Russell Hulse and Joe Taylor the Physics Nobel Prize of 1993.

## 6. Experiment design

Pulsars became an instant world-wide industry both for observers and theorists. Refined experiments were designed to observe periods, period phase-shifts, pulse and sub-pulse structures, Galactic dispersion. Massive survey programmes of ever-increasing sophistication were undertaken, are still running and are still being designed; thousands of pulsars - rotating neutron stars - are now catalogued. The development of multi-beaming receivers, computer storage and speed has enabled the efficiency and sensitivity of these searches to be increased by orders of magnitude.

The industry has given new life to old dishes, such as those at Parkes and Arecibo. Experiment design comes into play via multi-beaming feeds for these dishes together with state-of-the art receiver ‘backends’, designed to systematically search all available sky for pulsars, carrying out at each search position on-line period-searching via signal-folding, and de-dispersion. The goal is to find pulsars throughout the entirety of the Galaxy, to map the dispersing medium, and to find the extreme rarities, the double, triple or multiple pulsar systems, perhaps neutron-neutron-star systems, which may yield further tests of or insights into General Relativity. Pulsar searches constitute one of the key elements in science cases for the next generation of radio telescopes, ASKAP, MeerKAT, and ultimately the Square Kilometre Array.