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Highlights of Radioastronomy from 1800 to 2007 (a personal selection)

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Abstract. I present my own selection of highlights in radio astronomy from the past two centuries, starting before the discovery of radio waves of celestial origin. The discovery of infrared radiation set the scene for future work in radio astronomy. Highlights mentioned here include the first detection of the sun in radio waves, and the detection of Jupiter, advances in technology including aperture synthesis, and Very Long Baseline Interferometry. Along the way, a number of Nobel Prizes were awared to radio astronomers.

Résumé. Je présente ici ma sélection de faits saillants en radioastronomie, commençant même avant la découverte des ondes radio. La découverte de rayonnement infrarouge a mis la fondation pour les futurs avancements en radioastronomie. Les découvertes mentionnées ici inclus la premiŕe détection en ondes radio du soleil, ainsi que la planète Jupiter, Je présente aussi quelques avancés techniques qui sont faits depuis les débuts de radio astronomie. Des radioastronomes ont reçus plusieurs fois des Prix Nobels pour leur travail en radioastronomie.

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1. Prehistory : Herschel and Hertz

The history of radioastronomy normally begins in 1932 with the detection by Karl Jansky of radio emission of extraterrestrial origin, but I prefer to go a bit further back in history. The stage was set for the discovery of celestial radio waves by William Herschel more than a hundred years before Jansky's experiments.

In 1800, Herschel discovered infrared radiation from the Sun. For the first time, it was understood that light has components that are invisible to the human eye, and that the heavens contain sources which radiate energy which cannot be detected by simple optical observation.

Nearly a hundred years later, in 1889, Heinrich Hertz demonstrated the transmission and detection of long wavelength electromagnetic waves. He naively thought this was a mere curiosity and that it would have no practical purpose! Today we are surrounded by technology based on "Hertzian Waves" for communication and observation. One can hardly imagine a more incorrect prediction from such a clever fellow!

2. Detection of the Sun in Radio Waves

At the turn of the 20th century, only several years after the experiments by Hertz, attempts were made to detect the Sun in radio waves. It was a natural experiment to make, but it would hardly have seemed so natural if not for the work of Herschel in 1800. The demonstration that the Sun emits invisible radiation opened the way for experiments across the electromagnetic spectrum.

The attempts in the early 1900's by Oliver Lodge, Nordmann, and others were unfortunately unsuccessful. Their equipment was not sensitive enough, and they were unlucky to be observing during solar minimum. One might propose Lodge as the Father of Radio Astronomy, but then, like now, a positive detection is required before a discovery can be claimed. Nevertheless, he had the idea first, and deserves credit as a pioneer of radio astronomy, as he is already acknowledged to be a pioneer of radio techniques.

3. The First Detection of Radio Waves of Celestial Origin

Karl Jansky was a research engineer working at Bell Labs in the 1930's. While characterising his radio antenna, he detected sources which, the following day, appeared exactly four minutes earlier in time. This is the signature of a celestial source which appears overhead every Earth revolution. Jansky was very careful with his observations, and showed that he had detected the galactic centre at the radio wavelength of 15m.

Jansky published his result in 1935, so finally, thirty years after first attempts were made, a celestial object was detected in radio waves. Jansky is often considered to be the Father of Radioastronomy, and the basic unit of flux from radio sources honours his name.

The first detections of the Sun in radio waves were made in 1936, but they were not recognised for being solar radiation. During the solar maximum of 1936, many radio receivers were detecting unaccountable static, but no one attributed it to the correct cause at the time. In 1942, J.S. Hey detected the Sun at a wavelength of 1m, and showed that the emissions were correlated with sun spots. As this was wartime, Hey could not publish his results until 1946. His work was related to the war time RADAR developments, and any publication, even purely scientific, would have revealed to the enemy the level of technology developed for RADAR. Other detections of the Sun were also made in this period, including that by Grote Reber which he published in 1944, and by Southworth in the USA with his detection at wavelength of 1cm, and his demonstration that the radio emission from the Sun was thermal radiation.

4. Grote Reber : The Father of Radio Astronomy

Grote Reber, an American, contacted Jansky with the request to work with him in radio astronomy, but Reber was disappointed to hear from Jansky that he was no longer working on the subject. Jansky had been reassigned to other tasks at Bell Labs, and radio astronomy had remained essentially dormant for the ten years that followed his publication. Grote Reber, took it upon himself to advance the subject. He built a 31ft radiotelescope, nearly 10m in diameter, in his own backyard and made the first ever radio map of the sky. Reber continued publishing his observations for many years, and is most often considered to be the true Father of Radio Astronomy.

5. The 1940's and 50's

Up to this point, all radio observations had been made in the continuum and no line emission had yet been detected. Indeed, it was generally believed that no atomic transitions existed which would produce line emission in the radio band. In 1945, van de Hulst suggested the possibility that neutral atomic hydrogen could produce line emission from the spin-flip transition in which the proton and electron spin axes flip from parallel to anti-parallel, thus emitting a photon of very low energy, corresponding to a wavelength of 21 cm. The transition is very rare. Statistically, once in a million years, an atom of neutral hydrogen would undergo this spin flip transition, but van de Hulst correctly postulated that neutral hydrogen should be so abundant in the galaxy, that it should be possible to detect the 21 cm line emission. It would take several years before a detection was made.

Meanwhile, radio astronomy was marching along with advances in other areas. Angular resolution was improving so that by 1946, Hey, Parsons, and Phillips were able to show that there are discrete sources of radio emission, and not only extended emission from large regions in the sky. They had an angular resolution of 2 degrees, and by 1948, Bolton and Stanley improved the result with their angular resolution of only 2 arc seconds.

In 1947, Hey and Stewart were the first to use RADAR to illuminate celestial targets and detect the RADAR echo. They bounced RADAR transmissions off of the ionised tails of meteor showers, and were the first to demonstrate that meteor showers occur during the daytime, as well as during the night time.

All this time, a number of groups attempted to detect the 21 cm neutral hydrogen emission predicted by van de Hulst in 1945, including van de Hulst's own group based in Leiden, but it was Ewen and Purcell in the USA who finally made the first detection in 1951, and here was confirmation that neutral hydrogen is indeed enormously abundant in the Universe. It is the primordial material from which all structure in the Universe today was ultimately made.

6. A Golden Age of Radio Astronomy

The detection of neutral hydrogen with the 21 cm spin-flip transition started a golden age in radio astronomy. The 1950's and 60's saw the construction of many of the most well known observatories still in operation today such as Jodrell Bank, Westerbork, Parkes, Greenbank, Arecibo, and various instruments in Cambridge.

In the Netherlands, van de Hulst's supervisor, Jan Oort, was the driving force behind the push for the discovery of line emission in the radio which he wanted to use to probe the structure of the galaxy. He did so in the following years, and by the 21 cm emission in multiple lines-of-sight, he was able to reconstruct a model of the galaxy. Oort was the first to show that our galaxy, the Milky Way, has a spiral structure similar to that seen in optical images of many other galaxies.

Radio astronomy was also making advances in solar system observations, and in 1955 Burke and Franklin made the first detection of the planet Jupiter in radio waves. This was done at a frequency of 22 MHz, and they observed variable emission from Jupiter. In 1958, Sloanaker measured the 3 GHz flux from Jupiter which was highly polarised. Jupiter is producing synchrotron radiation from the charged particles in the solar wind spiralling down the very strong magnetic field lines of Jupiter.

By 1965, the giant dish at Arecibo in Puerto Rico had been running for a couple of years, and one if its earliest results was the surprising detection of the true period of rotation of the planet Mercury. Using the powerful RADAR at Arecibo to transmit a signal and then to detect the echo from the surface of the planet Mercury, Pettengill and Dyce determined the rotation period to be 59 days. Until that time, it was generally accepted that Mercury always showed the same face to the sun, and so had the same rotation period as its orbital period of 88 days. This gave the image of Mercury as a split world with a firey hell on one side, and intense cold on the other. It turns out that Mercury has a $2:3$ ratio of its spin period to its orbital period, and so every part of the surface of the planet has its time in the sun.

In the same year, a much smaller radio telescope was measuring the temperature of the sky in different directions, and stumbled upon the most important discovery in the field of cosmology. The horn antenna used in the 1960's by Bell Labs engineers was originally designed for radio communications with the satellites Echo and Telstar. It was afterwards taken over by Bell Labs radio astronomers who wished to make a general survey of cosmic microwave radiation. While doing a precise characterisation of the horn antenna, this led to the discovery of the Cosmic Microwave Background winning a Nobel prize for Penzias & Wilson. The Cosmic Microwave Background, which is visible in any direction in the sky, is evidence of the radiation left over from the Big Bang at the earliest times in the Universe.

In the latter half of the 1960's, Martin Ryle and Anthony Hewish at Cambridge had introduced and developed the technique of aperture synthesis, in which multiple antennas are joined together to work as a single instrument, using also the rotation of the Earth to effectively multiply the number of antennas involved in the observation. The 2048 dipole aperture array telescope called the 4-acre array at the Mullard Radio Astrophysical Observatory of the University of Cambridge was built to study scintillation in the interplanetary medium due to the solar wind. In 1967, Jocelyn Bell, using this instrument, detected regular pulses which she was able to demonstrate were not man-made, and definitely had a celestial origin. This was the discovery of pulsars which later study showed to be very dense neutron stars spinning extremely rapidly, with each pulse corresponding to the beam sweeping across our field-of-view, much as a light house periodically illuminates the coast as its light sweeps around.

It was natural to extend the idea to use interferometry to much larger separations of the antennas. As the antennas are separated by larger distances, the angular resolution improves. The technique of Very Long Baseline Interferometry (VLBI) was achieved for the first time in 1967 by a number of groups. The main difference with VLBI is the fact that the signals are recorded, and the correlation between the antennas is done afterwards. This technique demands not only a large storage capacity, but also very precise time keeping in order to put the signals together synchronised so that they effectively combine to make a single instrument. This was achieved by three groups working at the same time including Broten et al in Canada who achieved results with telescopes separated by thousands of kilometers. Moran et al from the Massachussetts Institute of Technology published results only a few months later. At the same time, Brown et al in Florida were measuring bursts from Jupiter at very low radio frequency using the technique of VLBI.

7. More Nobel Prizes : Gravitational Waves, and the Cosmic Microwave Background

In 1974, Taylor and Hulse using the giant Arecibo telescope discovered a pulsar which was in orbit around another neutron star. This binary system proved to be a perfect laboratory for testing one of the predictions of Einstein's General Theory of Relativity. After many years of monitoring the timing of the pulses from this system, Taylor and Hulse were able to deduce the orbital parameters of the system, and most importantly, to demonstrate that the distance between the two stars was reducing at a rate exactly predicted by Einstein's theory, and that the system must therefore be producing gravitational waves. It was the first demonstration of the existence of gravitational waves, and it earned a Nobel prize for Taylor and Hulse in 1993.

At higher radio frequencies, the measurements of the Cosmic Microwave Background (CMB) continued, this time from a space based instrument called the Cosmic Microwave Background Explorer (COBE). This instrument measured the temperature of the CMB to very high precision, and also measured the uniformity of the CMB across the sky. The result, that the CMB is uniform to within one part in 10 million, confirmed the validity of the Big Bang cosmology theory. The tiny variations on the temperature from point to point on the sky were also measured, and this gave an indication that the origin of structure in the Universe is from the tiny variations in the primordial plasma which existed in the very early Universe just after the Big Bang. The results of the COBE satellite merited a Nobel prize for the principal scientists involved, John Mather and George Smoot. Observations of the CMB continue to be the primary method for testing our theories of cosmology.

8. The First Known Extra Solar Planet

Up until about fifteen years ago, the only planets known to us were the ones in our own solar system. Although it seems natural that there should be planets around other stars, it wasn't until 1991 that a planet was discovered orbiting another star. This discovery was made by Alexander Wolszczan using the Arecibo radio telescope and measuring the variations in the arrival times of the pulses from a pulsar. Wolczan deduced that the wobble in the pulse times was due to the pulsar orbiting about the centre of mass in a planetary system with two Earth sized planets. It was a big surprise to find planets around a pulsar which is the remains after a violent supernova explosion, but there they were!

9. Summary and the Future

I have presented here a few highlights from radio astronomy from the earliest attempts up to more recent, Nobel Prize winning discoveries. These are just a few of the advances to our understanding made using radio astronomy techniques. The future will have many more, especially with the construction of the new giant telescopes coming soon such as LOFAR, ALMA, and the SKA which will be presented in later lectures.