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THE CANADIAN VERY LONG BASELINE INTERFEROMETER

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On the stars seen in the sky, with the unaided eye, many, when seen with a telescope, are found to be double,- that is to have a compsnion close by in the sky.

Also, many of the stars which seem to be single, when viewed through a small telescope, are seen to be double when viewed through a larger telescope.

In the middle of the nineteenth century, an English astronomer, W.R.Dawes, gave to his gentle readers the nice comfortable rule that the minimum angular separation (in seconds of arc) which could be noticed by a telescope of diameter D inches was theta equals to 4.6 divided by D.

It was not long before diligent observers complained to Mr Dawes that his formula was not uniformly accurate.[1] He hastened to explain that his formula was for yellow stars; that for blue stars, theta equals 3.3/D, and for red stars, theta equals 5.8/D, or, in general, theta equals 2.1(lambda x 10^5) / D, where lambda (the wavelength of the light from the star) and D, are measured in the same units (i.e either both in inches or both in centimeters).[2]

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1. For instance, with a 4-inch telescope one could see two blue stars one second apart.† One would need a 6-inch telescope to see two red stars one second apart.‡

2. For blue stars, lambda equal $4_5 \times 10^{-5}$ cm.; for red stars, lambda equals 7×10^{-5}

†e.g. Gamma Lupi ‡e.g. Eta Geminorum

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When it was first aired in the press that the ~~One hundred years ago, when it was pointed out that the~~ power of resolution of a telescope was proportional to the wavelength of light divided by the diameter of the telescope, most persons just said: "very interesting",- and went on with what they were doing.

But seventy years later, this proportionality played an important role in the foundation of radio astronomy.

In the year 1933, Grote Reber, a radio engineer, of Wheaton (Illinois), ~~by day~~ worked for a radio manufacturer in Chicago. In the evenings, at home, he read technical literature. ~~in his field.~~ In the Proceedings of the Institute of Radio Engineers (vol.21, 1933, pp 1387 ff) he read an article entitled "Electrical Disturbances Apparently of Extra-Terrestrial Origin". The paper was by Karl Jansky (1905-1950), a research engineer at Bell Telephone Laboratories in New Jersey. Jansky, in tracking down the sources of static, had come across a slight hiss which he adjudged to be extra-terrestrial because it moved across the sky as the earth rotated on its axis.

Reber started wondering how he might best receive these waves. With the thought that radio waves and light waves were the same ~~expect~~ except for their wavelengths, he considered how the astronomers gathered the light from stars.

The large optical telescopes consist of a parabolic mirror which bends the incoming rays and forms a real image at the focus. The eyepiece magnifies this image. Why not, thought Reber, build a paraboloid that would reflect radio waves, bring them to a focus, and lead them off to an amplifier ?

He ~~had~~ owned a radio receiver that received well on the 2-metre band. He had a back garden about forty-feet wide. He could build a 30-foot paraboloid. With the lambda over D formula this would give him a resolution of about 12 degrees,- very poor compared with optical telescopes, but, at least, it would enable him to know whether the waves came from this or that constellation. ~~He built~~ It took him six years of spare time to build for himself what was, in fact, the first radio telescope, and the prototype for ~~all~~ its early successors.

In 1940, he ~~had~~ communicated his first results, and interpretations, ~~printed in the~~ to the I.R.E. (Proceedings of the Institute of Radio Engineers, vol.38 (1940), 68). He interpreted the radiation which he received as due to thermal emission from ionized stellar gas. He found it strongest in the constellations of Cassiopeia and Cygnus.

When the United States entered the War (in December 1940), his private researches came to an end. He was given a job at the Naval Research Establishment at Washington.

After the war, Radio telescopes began to spring up all over the world. It was known that for good resolution they should be large and be operated at small wavelengths.

~~In 1952,~~ Manchester University[1] ~~began to build~~ built a 250-foot dish at Jodrell Bank (Cheshire), about 30 miles from Manchester. ~~It~~ after 5 years' work it was ready for operation in 1957, designed to operate on 1 metre wavelength. It could distinguish objects 44 minutes (of arc) apart. Later, adjustments were made to it so that it could operate on 21 cm.wavelength giving a resolution of 9 minutes of arc.

In 1964, a 1000 foot dish came into use at Arecibo (in Puerto Rico). (It is operated by Cornell University). It is not steerable, but is fixed in

1. With financial aid from Lord Nuffield.

a hollow in the ground. On 1 meter wavelengths it has a resolution of 11' and on 21 cm. wavelength, 2'.

Meanwhile, the principle of interferometry was being used. At Cambridge, in England, they have two 60 foot dishes one mile apart (and a third that moves up and down on rails). They are joined to one receiver. By recording the times of maximum and minimum flux reception of the and the time of fringe interference, measurements can be made to about 26 seconds of arc, on the 21 cm wavelength

In 1966, the telescope at Jodrell Bank was connected by a cable to an instrument at the Royal Radar Establishment, at Malvern (Worcestershire) about 60 miles away. Measurements were made to about 0.5 seconds of arc. However, there were indications that there were slight losses in the linkage. The astronomers advised against trying cable links longer than 60 miles.

In Australia and the United States, microwave links were tried. They were found impractical for distances over 200 miles.,- but not until measurements had been made to about o.15 seconds.

At the Dominion Astrophysical Radio Observatory near Penticton, there is an 84-foot paraboloid, (since 1960) and at the Algonquin Park Radio Observatory a 150-foot (completed 1966) dish. They are about 2,000 miles apart; Used together they would make a great interferometer. Accurate results would not be obtained if they were linked by cable or by microwave.

A solution was thought of, simple in concept, but not so simple in execution: make simultaneous video tape-recordings and play them back in unison. Many heads were put together, and last year the system was made to work. A specific problem was chosen, to measure the diameter of the brightest quasar, 3 C 273. The result ~~xxx (obtained at 67 cm/xxxx wavelength)~~ was modestly announced as being "less than 0.02 ~~0x2~~ seconds of arc". Before the year was out, the maximum diameter of eight more quasars were measured. In June of this year a team of Canadian astronomers ~~were~~ was invited to England, and using the Jodrell Bank telescope and the Algonquin telescope, 3200 miles apart, ~~measurements were~~ made to ~~0xix~~ < 0.01 seconds of arc,- which is better than the ~~xxxx~~ 200-inch optical telescope at Palomar can do.

The radiation from Quasars is synchroton radiation. That is, it is due to particles with relativistic speeds in a magnetic field. It is recognized by the fact that its flux density increases with the wavelength on which it is received.

But the power of resolution of the telscope decreases with increase of wavelength . Thus one ~~ix~~ has to make a choice between a weak signal and good resolution or ~~x~~ a strong signal and ~~xxxx~~ not so good resolution. The Canadian Very Long Base Interferometer struck a good compromise in working at a wavelength of 67 cm.

In the early years of radio astronomy some radio sources were identified as distant galaxies and some as interstellar clouds and some went unidentified.

The possibility of any of the unidentified radio sources being ordinary stars was ruled out after all radiation from the sun had been thoroughly studied for about ten years. The sun is an average star. Its radiation, on radio wavelengths, is so weak that if it were moved away to the distance of the next nearest star, we could not receive its radiation with our present antennae.

In the year 1960, Cambridge found a strong source of synchroton radiation coming from the general direction of a sixteenth magnitude star. They catalogued it as 3C48 and asked Palomar to have a look at the star with the 200-inch telescope.[1] Palomar found that the star seemed to be surrounded by nebulosity. A spectrum of the star was taken. The spectrum did not look like the spectrum of a star nor of a galaxy. It was a puzzle. The object was called a quasi-stellar object, or, a quasar.

In 1962, Cambridge found the source 3 C 273 near to a 13th magnitude star.[2] Again the 200-inch telescope showed the source as a star immersed in nebulosity. A spectrum was taken; it was unrecogniable, until Maarten Schmidt got a brain wave. Maybe the line at 3239 angstrom was the ultra-violet ionized line of magnesium 2798.[3] If it was, it was red-shifted 0.158. With this supposition, the other lines were explainable.

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1. 3 C 48: $1^h\ 35'\ +33°$ Between Alpha Tri. and Beta Andr.

2. 3 C 273: $12^h\ 27'\ +02°$ in Virgo

3. which had shown on a spectrum of the sun taken from a rocket fired above the atmosphere.

Going back to the spectrum of 3 C 48, it was found that it could be explained by supposing a redshift of 0.368.

Morev than 150 quasars are now catalogued and more than 100 have had their spectra photographed. Their redshifts vary from 0.131 to 2.223. If their redshifts indicate recession, and if the rate of recession increases (according to Hubble's law) with distance, ~~theyxare~~ the nearest is about 2,000 million light years away and the furthest 8 or 9 thousand million light-years away. There is not universal agreement as to what these Quasi-stellar objects are, but the commonest opinion is that they are distant galaxies, and that the starlike object is their nucleus. If they are distant galaxies, their luminosities must be around 10^{46} ergs per second (about 10^{13} times that of the sun)

The interferometers have shown that ~~their~~ the radio emission of quasars comes from very small regions - usually one at either side of the optical object. ~~- and which that~~ If we see only one, it is possibly ~~depends on whether~~ because we are seeing ~~them~~ the quasar end on - not ~~or~~ side on.

In 1964, it was found(at Cambridge) that radio waves from quasars scintillate, and that those from ordinary radio galaxies do not. The scintillation is more noticeable at meter wavelengths than at centimeter wavelength. Accordingly, at Cambridge, there was built an antenna to operate on 3.7 meter wavelength. It is a rectangular array spread over 4.5 acres furnished with with 2,048 ~~dipoles~~ collecting elements, each connected to the centre of the array by coaxial cable. (It is as effecTive as a 2,000 foot paraboloid) The reception beam is steered in elevation by phase-scanning, and the sky is swept from west to east by the rotation of the earth.

From the recorder of this telescope there flows more than 50 feet of paper a day. Immediately after it began work, towards the end of July of last year, the task of analyizing the record fell to a graduate student from Dublin, Jocelyn Bell . On August 6th, Miss Bell noticed something unusual. In the middle of the night (when scintillation is usually low) there was rapid scintillation from a weak source. It was so regular, so unlike signals from quasars or from radio galaxies, that Miss Bell called the director of the project, Dr Hewish. It was so regular that Dr Hewish suspected interference from something on earth. Meanwhile there was nothing to do but to wait. The instrument was combing the sky; it would be back at that location in about a month. Sure enough, about a month later, Miss Bell broke the stillness of the Night; with the words "Its back". They called it Joceyln's Little Green Man until two more were discovered; it was then given its catalogue title of CP 1919.[1] They ~~were~~ are all spoken of as Pulsars. CP 1919 has a period of 1.337 301 seconds. From ~~appearance~~ observation to ~~appearance~~ observation, its period does not vary a millionth

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1. It is in the constellation of Vulpecula, the Little Fox.

of a second. It is more regular than any man made chronomometer. Since February, CP 1919's existence and properties have been verified in the United States, in Australia and at Arecibo. There are now nine Pulsars known: six discovered at Cambridge, two at Parkes (Australia) and one at Green Bank (W.Va.). Their periods (constant for each one) vary from 0.25 to 1.96 seconds. They are all from sources within our galaxy, lying between 200 and 1700 light years away.

There has been much speculation as to what these Pulsars are, there have been almost as many suggestions as there are astronomers. They do not seems to be planets; none of them show any sign of revolution around a primary, or of eclipses, or of occulations. They do not show optical emission. This suggests that they are fuel-depleted,- something like White Dwarf stars (which are as heavy as the sun, but less than one-tenth of its diameter). If they are, they must be either pulsating or rotating rapidly. With a very dense star, the rotation would be more probable. For the present, I think of them as Mini-White Dwarfs, rotating rapidly.