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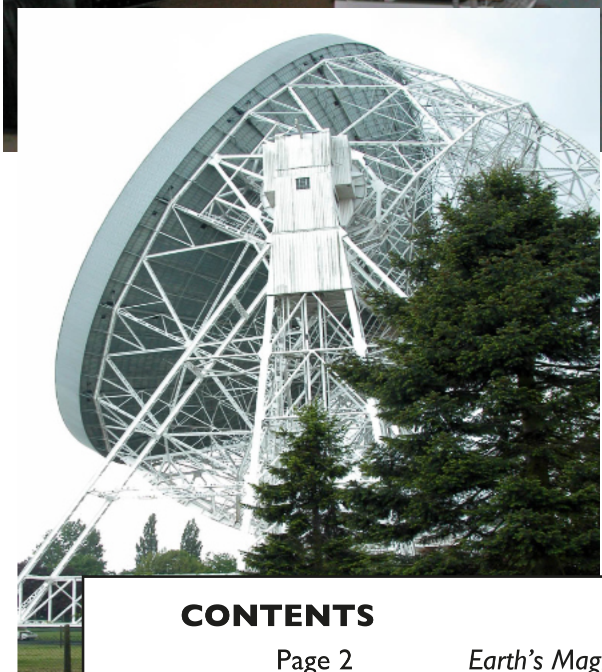

Astronomy with a Satellite Dish?

Mark Edwards tells you how to receive signals from space with a little smaller receiver dish and slightly cheaper equipment. Also in this are two stories by Paritosh Maulik on the Earth's Magnetism, Solar Radiation and Aurora and Cosmic Rays

Views of the Jodrell Bank Radio Telescope from the Control Room and from the Arboretum during the visit by the C&WAS in May 2003

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Earth's Magnetism, Solar Radiation and Aurora

By Paritosh Maulik

Both experimental and theoretical results in the late 1800 and early 1900 suggested that Earth's magnetic field can react with charged particles from the Sun. James Van Allen of Iowa University, USA, sent instruments aboard an artificial satellite in the late 1950's and found that there are two doughnut shaped well distinct radiation zones covering the Earth, *Fig 1*. One

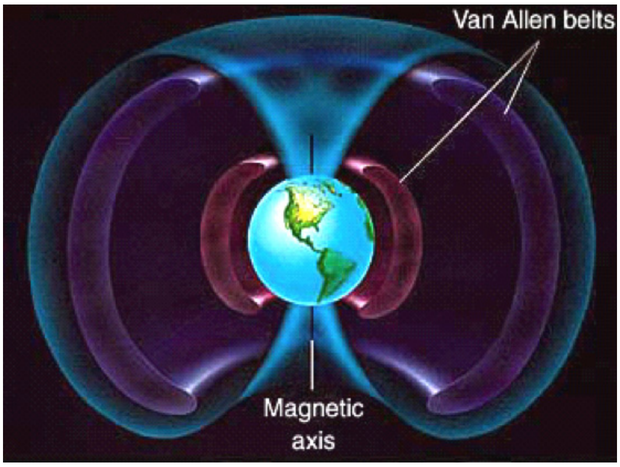


Fig 1. Van Allan belts around the Earth.

is at about 3000km and the other is about 20,000km above the Earth. Apart from leaving a small gap near the North and south Poles, these two zones nearly surround the Earth. These two radiation zones covering the Earth are called the Van Allen belts. Earth's magnetic field prevents majority of the charged radiation reaching the Earth and protects us from radiation damage. Interaction between these charged particles and the magnetic field also gives rise to aurora.

Earth's Magnetic Field

As a first approximation, we can assume the Earth to be a giant bar magnet with its axis nearly aligned with the spin axis of the Earth, *Fig 2*. The molten iron core of the Earth is responsible for the magnetic behaviour of the Earth. Magnetic field lines indicate the strength and direction of the magnetic field. In the case of the Earth, it runs from south to north. Earth's magnetic poles are not fixed; they change with time, even daily, depending on the Solar activity. This displacement may be as high as 80km and can follow an irregular oval path. Currently the Earth's North magnetic Pole lies in Canada and according to 2005 data, somewhere near 82.7°N 114.4°W. Similarly the Magnetic Pole is in the Antarctic somewhere around 65°S and longitude 139°E

Gasses in the corona of the Sun move outwards at the rate of about 1 million tonne per second. The temperature the corona is about 1°-2° million C. This high temperature causes gases to ionise into charged particles like electrons, proton and alpha particles. Also in addition there are electromagnetic radiation and neutral particles.

These charged particles travel towards the Earth at a speed of about 300-400km per

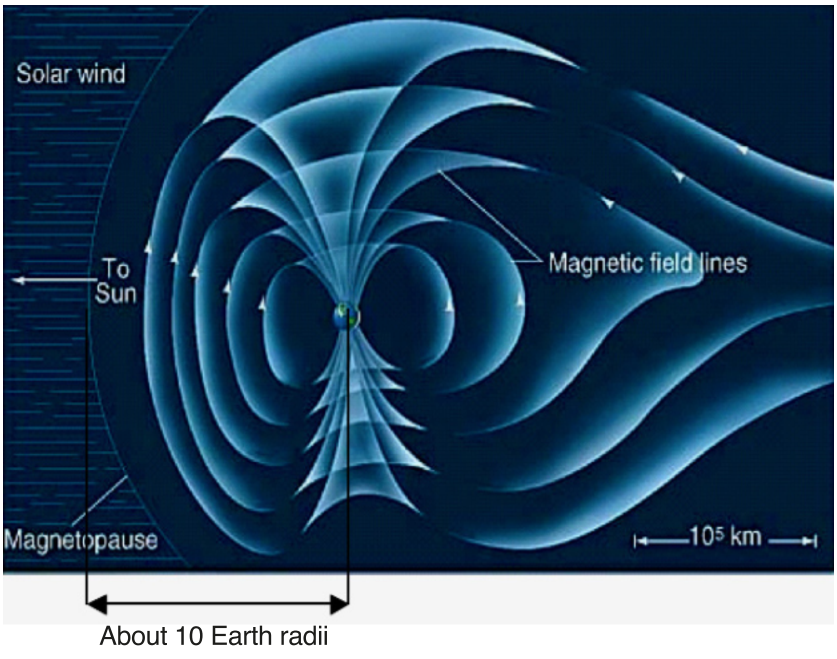


Fig 2. Earth's Magnetic Field

second. During a solar flare, a massive flow of materials leaves the Sun at about 800-1000km per second. It takes about 48 hours for these particles to reach Earth.

Electromagnetic radiation and neutral particles do not interact with magnetic fields and travel to Earth, but Earth's magnetic field prevents charged extraterrestrial particles reaching the Earth. This magnetic field takes the shape of a bubble or cavity around the Earth. This boundary is called the magnetosphere. Earth's magnetic filed is not symmetric around the Earth. From satellite mapping we now know that the particles around the Earth are distributed in a distorted tear drop shape. High energy particles of the Solar wind squash the magnetic field (magnetosphere) on the sunlit or daytime side of the Earth and on the other side it can extend beyond the orbit of the Moon.

The term "sphere" mainly refers to the sphere of influence. We have to remember that the magnetic field of the Earth is weaker than a fridge magnet, yet it can drastically reduce these energetic particles entering the Earth's atmosphere. Apart from Venus and Mars all other planets have such a magnetic shield. Only Pluto remains unknown; the recently launched NASA probe is likely to provide the answer.

When the solar wind meets the magnetic field of the Earth, it slows down to subsonic speed and heats up. The majority of the Solar wind is deflected around the Earth, but a portion is reflected forward to the incoming wind. The situation is like a stone in a moving stream. In front of the stone there is a bow wave and behind is an eddy formed by the incoming flow and the reflected flow.

The Solar wind or these energetic particles form only a minute fraction of the total energy received by the Earth from the Sun. Out of these only about 0.1% of particles penetrate the Earth and the majority is deflected from the Earth. The charged particles are mainly electrons and protons. These particles follow a spiral path, *Fig 3*, around the magnetic lines of force and are trapped into tight regions around the Van Allen belts. Lighter electrons mainly occur in the outer belt and the heavier protons mainly reside in the inner the belt. Some the charged particles follow the magnetic path of the magnetosphere in a large scale circulation of particles in the magnetosphere. Since there is a large concentration of magnetic particles along the Van Allen belt, crossing this barrier causes severe radiation damage.

Satellite mapping has also shown that there is another radiation zone just inside the inner belt. This is the anomalous cosmic rays, see *Comic Rays* in this issue. These are partially ionised particles of nitrogen, neon and oxygen originating in extra-solar explosions.

We shall now come to the interaction between these charged particles and the Earth's magnetic field. This interaction gives rise to one of the most spectacular show on the Earth, the Aurora. However the occurrence of aurora is not exclusive to the Earth, and does occur in other planets as well.

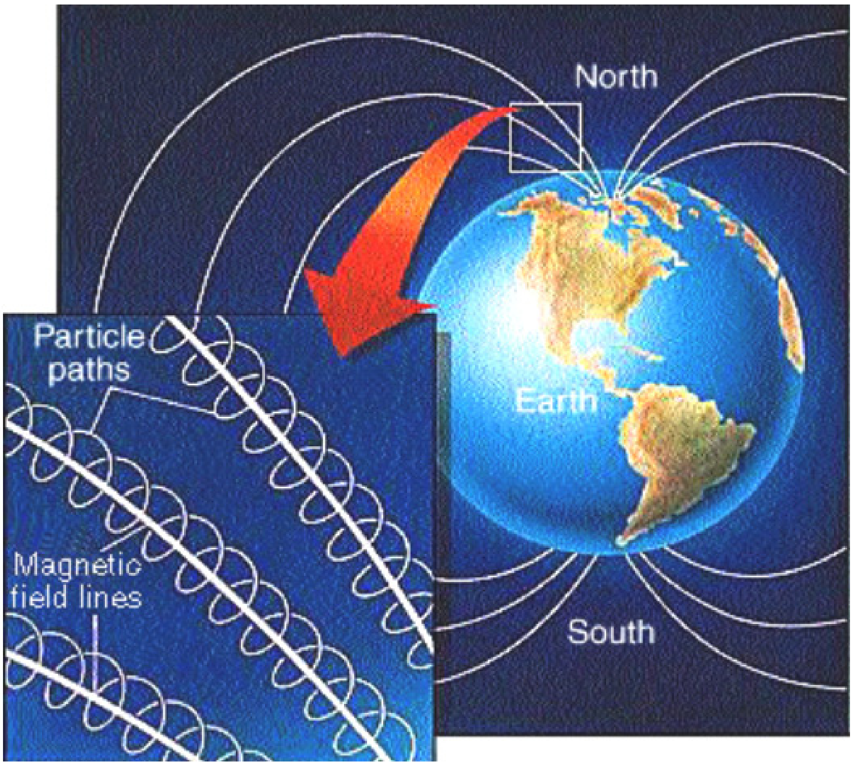
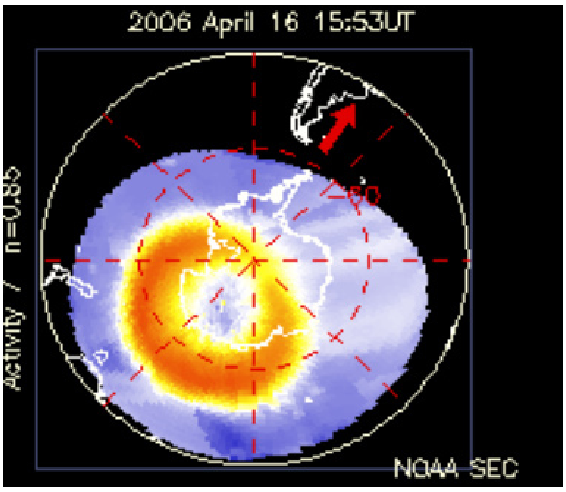


Fig 3. Spiral path followed by the charged particles along the magnetic filed lines.

(Hu) Man made "Aurora"

In 1896 Kristian Birkeland in Norway placed a sphere painted with fluorescent paint in a low vacuum chamber. Inside the sphere he placed an electromagnet. Thus the sphere simulated the magnetic Earth and the vacuum chamber outer space respectively. Then he



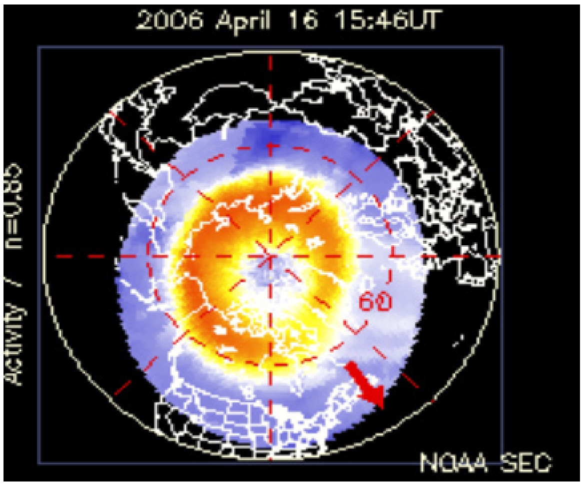


Fig 4. Aurora oval over the southern, (left), and northern, (right), hemispheres on 16th April 2006, 15.30h UT. Space Environment Center, USA

sent a beam of electrons towards the sphere, the electrons curve towards and around the magnetic poles and also produced some of the features of aurora.

In 1990, an American experiment released vapours of metals like barium calcium, lithium and sodium. Vapours of these elements when interact with the ultraviolet rays of the Sun, they change from the neutral atoms to positively charged ions, but at different rates and also they absorb Solar radiation and re- emit at different wavelengths. These are visible from the Earth. This experiment allowed us to study the shape of the Earth's magnetic field. If the released vapour is not ionised atoms, but neutral atoms, they appear as spherical cloud and do not follow the magnetic field.

In another experiment, high velocity electrons were released in the atmospheres. This process simulated aurora by making the air glow in red and green. Atmospheric nuclear tests also produced aurora. Once it was suggested that if a nuclear device was exploded near the inner radiation belt, it would be an interesting experiment to study the effect of particles from explosion on aurora. But the US military pointed out that such a release may have devastating effect on orbiting satellites and radio communications; this project was abandoned

Aurora

Although some of the Greek historians have recorded aurora, it is not very usual to see from such low latitudes. It is common in both high northern and southern latitudes. Since the high southern latitude is sparsely populated, most of the reported sightings and folklores to explain aurora comes from north. Some of these were naturally linked to sprits and according to fishy tails of the Scandinavia countries; aurora is the reflected light from shoals of herring swimming close to the surface. At later dates aurora was explained as reflection of sunlight by snow particles in the atmosphere.

At one time people believed that the further north one travels, one can see more aurora. But eventually it became clear that maximum aurora occurs in an oval shaped band of about 500km wide and 2000km from the poles and aurora occurs every night in this zone. It was also found that high aurora activity occurs during high Solar activity. During the International Geographical Year in 1957-58, hundreds of thousands of images of aurora was collected and it became clear that the oval shaped band of aurora is centred on the Earth's Magnetic pole.

Since the radius of the aurora oval and that of the Earth are much greater than the height of the aurora, from the ground we see only a part of the aurora and it appears as a sheet hanging from the sky. However images from space have shown the full oval shape of the aurora, *Fig 4*. These image also suggest that aurora occurs about 100-250km above the ground, but can occasionally can reach a height of 400km. Astronauts passing through aurora have reported light flashes even with their eyes closed. This is due to charged particles from aurora passing through the eye.

Rockets carrying particle detectors have shown that electrons with energy level of about 6keV when strikes the upper atmosphere with a velocity of about 50,000km per second, air particles ionise and it appears as aurora. A current of about 1 million ampere can flow along the aurora oval. This is lot of power; a good few

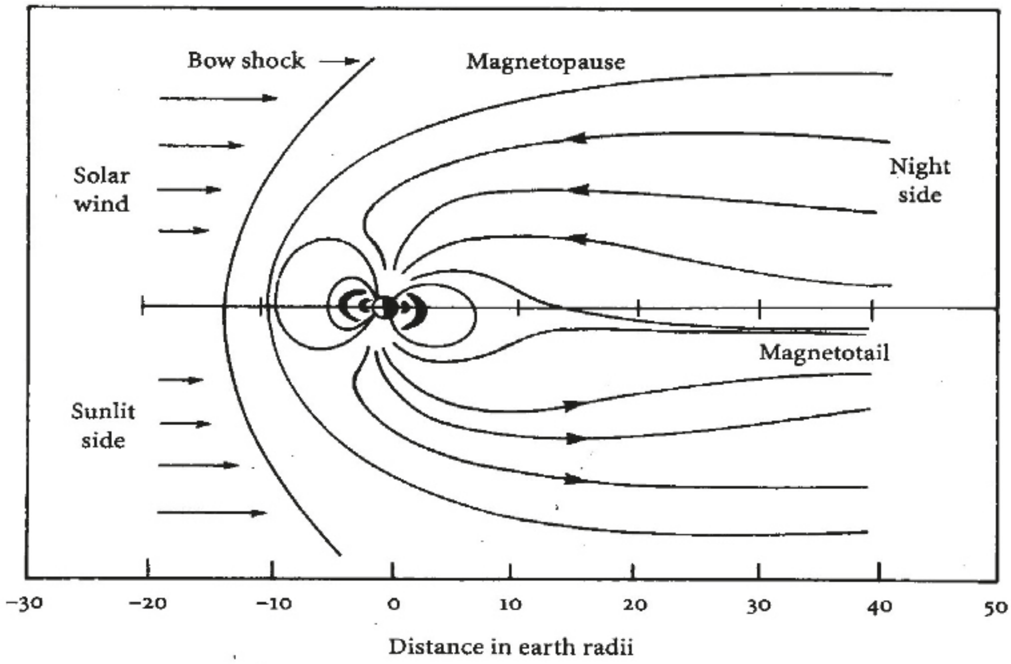


Fig 5. The magnetosphere around the Earth. Two dark patches near the earth are Van Allen radiation belts. (*Sun, Earth and Sky*, K R Lang, Springer-Verlag, 1997)

years of annual electricity consumption of a very energy hungry country.

When electrons with such high energy collide with nitrogen and oxygen in the rarefied upper atmosphere, the gas atoms gain energy and then release the energy in the form of light. Exited oxygen atoms give green and red colours. The red colour requires excitement to a higher energy level and hence is not such a common event. This is why most of the time aurora appears to be green. Un-ionised nitrogen gives a pink colour at the bottom of the green colour. Ionised nitrogen causes blue or violet colour, but these are not very common either.

Since auroral activity increases with the Solar activity, it is naturally to think that the electrons involved in the formation of aurora come directly from the Sun during the high Solar activity. Electrons trapped in the Van Allen belts do not have enough energy to form aurora. It is more likely that the electrons held in the earth's magnetic tail causes the aurora. Earth's magnetic field energises these electrons. Such a process can take place four to five times a day. Coronal mass ejection from the Sun increases the magnetic activity around the Earth. This is the reason that aurora and the Solar activity are linked.

Now to sum up, the Earth behaves like a giant bar magnet, but the poles of this magnet are not fixed, but rotates with time. The magnetic field of the Earth is not symmetrical, but is like a tear drop in shape. This magnetic field traps the energetic particles from the Sun and prevents them from reaching the Earth. There are two zones around the Earth *Fig 5*, where most of these particles are held. These two zones are called Van Allen belts. But some of the particles flow the asymmetric magnetic field in large scale convection currents. This process increases the energy of the particles. When these high energy particles hit atoms of oxygen and nitrogen in the upper atmosphere, the gas particles gets exited and release the excess energy in the form of aurora. Solar activity increases the Earth's magnetic activity and also increases the auroral activity.

A joint European - NASA project SOHO is monitoring the Sun collecting images and data. Another Chinese - European mission project consisting of five space crafts moving in unison, called Double Star, is collecting data on Earth's magnetic field.

Web address for up to date information on space weather

http://www.sec.noaa.gov/

Contact for aura activity (likely to close soon)

aurorawatch@tesla.dcs.lancs.ac.uk

Cosmic Rays

By Paritosh Maulik

Cosmic Rays are high energy particles from extra-terrestrial sources including the Sun. Like radioactivity, initially these were thought to be rays (photon). Rays such as light or x-ray or gamma-rays are not deflected by magnetic field, but charged particles are. Soon it was realised that both radioactivity and Cosmic Rays consist of rays (photons) and particles and not simply "rays". There are more than one sources of Cosmic Ray and some of the sources are yet to be understood.

In the early 1900's physicists began to realise that there is more to radiation than what could be accounted from the known radioactive sources. In 1912 German scientist Victor Hess took a Gold Leaf electroscope and later a Geiger counter in a balloon and climbed to a height over 5000m; (without oxygen). First there was a drop in radiation reading with height, as expected (moving away from Earth's radioactive sources), but then level of radiation increased again with the increase in height. This increase in radiation level with height was also observed during the night and Solar eclipses. The conclusion being, that radiation is entering the atmosphere and not only from the Sun, but from extraterrestrial sources as well. Hess was awarded a Nobel Prize for his discovery. In the early days, it was thought that this is an electromagnetic radiation; hence it was called Cosmic Rays. But in the 1930's it was realised that these are affected by the Earth's magnetic field and therefore are charged particles and not the part of electromagnetic spectrum.

These particles exist in a wide range of energy from Mev to GeV (10^6-10^9eV). This represents velocity of a proton to about 43% to 99.6% speed of light. In particle accelerators (such as at CERN) particles are exited to high energy levels and these are made to collide with other particles and the product of degeneration is studied. During 1930-50's particle accelerators were of limited energy, so Cosmic Rays were the only source of high energy particles and was used for the discovery of some of the sub-atomic particles.

The rate at which cosmic rays reach the Earth varies enormously with their energy and this is one of the major problems in the study of Cosmic rays. Low energy Cosmic Rays hit the Earth in abundance and can be of the order of many thousands per square metre every second. Cosmic Rays of above 10^{17}eV may enter the atmosphere about 1 per square metre per century, where as Cosmic Rays above 10^{20}eV may reach 1 per square kilometre per century.

However there is a phenomenon called Extensive Air Shower. As the high energy Cosmic Rays hit the upper atmosphere at about 20km above the Earth, it lets loose about half of its energy and creates a jet according to $E=mc^2$. These molecules, when interact with nitrogen or oxygen nuclei of the air, create more particles, and other elements. This mass of particles of energy level of about 10^{14}eV can come down to the ground level like a pancake about 1km diameter and a few metre thick *Fig 1*. These can be detected at the ground level. Therefore one needs a large array of detectors to detect the Cosmic Ray. Initial particles which start the shower is called primary Cosmic Rays and the particles formed by interaction is called secondary Cosmic Rays.

Satellite and balloon bourn measurements suggest that the majority of the Cosmic Rays are protons; however the presence of heavier elements like uranium nuclei have also been detected. The majority of Cosmic Rays are positively charged particles and about 0.1% of Cosmic Rays, gamma-rays. Gamma-rays carry no charge and are not affected by the galactic magnetic field; hence these are of interest to understand the source of Cosmic Rays.

Detectors Used

These are the heart of the instrument which detects the incoming "ray" and these detectors are sprayed over a vast area in the form of an array.

Scintillation Counter

This detector is made from a special plastic. When Cosmic Rays hits the plastic it gives off a light photon, which in turn is detected by a photo multiplier. The scintillator and the photo multiplier are housed in a dark box, so as to avoid any stray photon.

Water Cerenkov Detectors

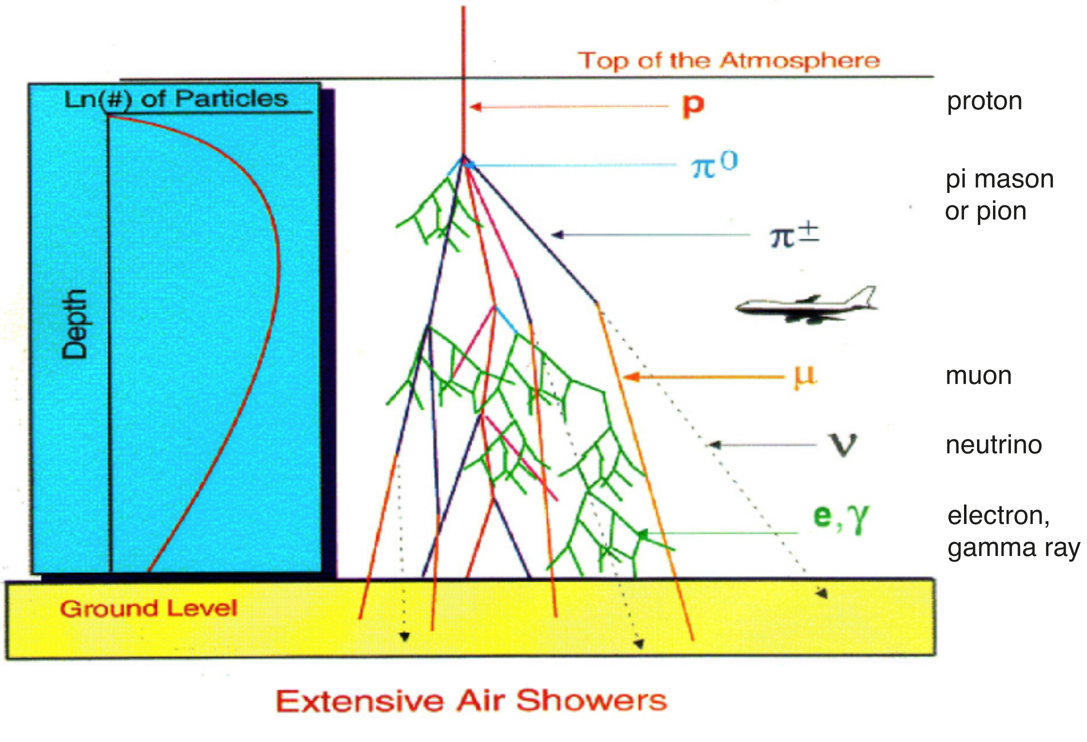
In these detectors, pure water, instead of scintillating material, is used. When Cosmic ray hits the water, it gives off blue light called Cernkov Radiation, which is picked up by photo multiplier. Sides of the water tank are reflective to reflect the radiation to the photo multiplier. The velocity of light in a vacuum is the highest possible speed and the speed of light is lower in other mediums such as air or glass or water. But if a particle like an electron or proton is travelling in the medium at a speed higher than that of the light in that medium, it emits radiation usually in the blue to ultraviolet range, called Cernkov Radiation. For example gamma-rays of the energy 10^{12}eV when they pass through the atmosphere, generates secondary electrons and optical telescopes can pick it up as blue light.

Solar Cosmic Rays

As the name suggests, these have their origin in the Sun. Energetic particles from a solar flare (sudden release energy from the Sun in the form of electromagnetic radiation and particles like electrons, protons and other atomic nuclei) and Coronal Mass Ejection (large release of matter by the Sun) are of the sources of Solar Cosmic Rays. These Cosmic Rays have energy of several hundred MeV to a few GeV. Solar Cosmic Rays mainly consist of mostly protons (H+), about 10% of He and <1% heavier elements.

The flux of Solar Cosmic Rays increases with increase of solar flare. This was detected in the early forties by Geiger counters, since then recorded data has been collected. These outbursts coincide with visible flares and can last for tens of minutes to hours. The magnetic field of the Sun can deflect Cosmic rays from extra-Solar sources. Cosmic rays entering the Earth follow the 11 year Solar cycle, but in the reverse order; during the high Solar activity, fewer Cosmic Rays enter the Earth. During maximum Solar activity, the magnetic field of the Sun extends to the interplanetary space and causes Cosmic Ray particles to deflect away from the Earth. When the solar activity is low the interplanetary magnetic activity of the Sun is also low, and more Cosmic Rays can enter.

There is some evidence that perhaps Solar activity may have some effect of the climate. William Herschel observed that periods with fewer Sunspots correspond to periods of lower rainfall and hence the higher price of grain. Attempts to correlate Solar activity and climate were not very successful, but perhaps there may be a trend with the climate change and the imprint of isotopes like C14, say in ice or in wood. These isotopes are the effects of Galactic Cosmic Rays. For example during the years 1000-1300, the solar activity was very



Break down of cosmic ray particles during the travel down the atmosphere. The horizontal axis of the graph indicates number of particles high; there was an increase in the C14 level and the temperature was warm. Vikings settled in Greenland. But after 1300, there was a drop in temperature, which was catastrophic for the Vikings and during this period there was a drop in the C14 level. This period is thought to be a Little Ice age. Then since about 1950 there is an increase in Solar activity and increase in temperature.

Recent satellite observations suggest that perhaps there is a relationship between cloud cover and Galactic Cosmic Rays. Clouds can reflect incoming radiation of short wave length Sun light, and have a cooling effect. Clouds on the other hand can trap radiation of longer wave lengths, thermal radiation, so producing a heating effect. Another important factor is the height of the cloud level above the Earths surface. Optically thin cloud, at high altitude, tends to heat. The mechanism of the effect of the intensity of Galactic Cosmic Ray on the cloud cover over the Earth is not quite clear yet

Anomalous Cosmic Ray

The source here is not the Solar system, but explosions like supernova or other similar phenomenon which ejects ions like nitrogen and neon. These elements are produced in stars, but not in the Sun. The Solar Cosmic Rays mainly contain electrons and protons. The ionisation state of the Anomalous Cosmic Rays suggests that these were originated in a less violent process. These have lower velocity than other cosmic rays and occur in a radiation zone surrounding the Earth.

Cosmic Rays in the Galaxy

Cosmic Rays, being charged particles, interact with the magnetic field, which exists between the stars and galaxies. This causes a change in the direction of travel from the source and hence identification of the source becomes impossible. However in some cases Cosmic Rays travelling at speed, close to that of light, interact with magnetic field and emit synchrotron radiation. This can be picked up say as radio synchrotron radiation; one such example is the supernova remnant Crab nebula.

Cosmic rays in collision with interstellar gas produce high energy (10MeV-1000MeV) gamma rays. Similar collisions also produce radioactive isotopes. Such particles have been detected with spectroscopy. Cosmic Ray particles eventually leave the Galaxy and escape into inter-galactic space.

Very High Energy Cosmic Rays

Cosmic rays of very high energy can travel virtually unimpaired by the galactic and interstellar space. These can be used to study the origin of the source. Binary star systems and supernova remnants have been suggested as the source of particles of up to about 10^{15}eV. But Cosmic ray particles higher than this energy level do exist, but their origin is not certain.

Energy levels of Cosmic Ray particles of the order of 10^{18}eV suggest the source to be very large or to have a very high magnetic field. If these sources are within the Galaxy, then these are relatively close to that the Earth. The magnetic field of the Galaxy is not strong enough to deflect these particles and therefore the Earth would see a high flux of Cosmic rays from the direction of the galactic plane.

It may be possible that the sources of high energy Cosmic Rays lie outside the Galaxy. For example, the nearest neighbouring galaxy, the Large Magellanic Cloud, is at around 170,000 light years away, hence such sources are possible. High energy Cosmic Ray from such source, during their travel, will interact with the Background Microwave Radiation leftover from the Big Bang. Calculations suggest that as a result of such interactions, Cosmic Rays of high energy would transform into gamma rays and sub-atomic particles; only cosmic rays with a maximum energy level of $4x10^{19}$eV would travel to the Earth. This is called GKZ cut off, but there are well documented proofs of such encounters, albeit limited in number.

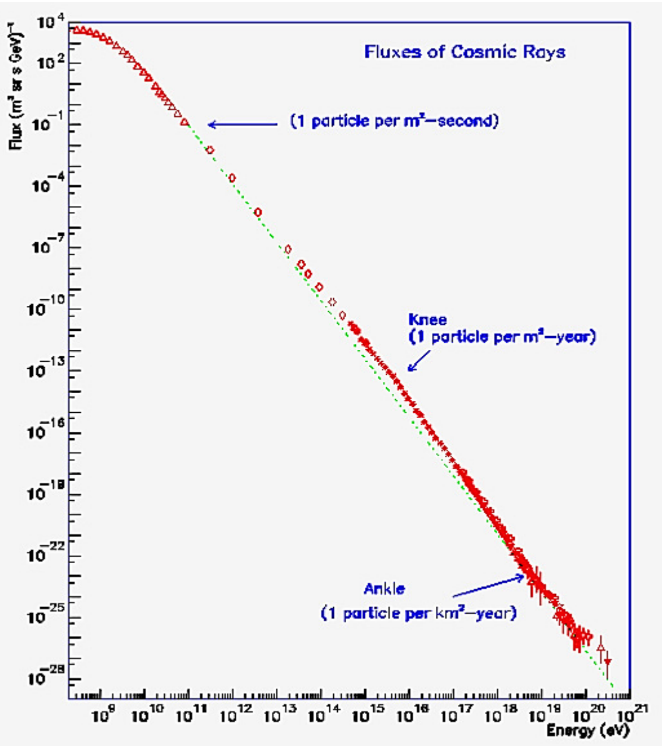
In the November, 2005 issue of the *Astronomy Now*, Chris Kitchin has discussed some of the issues related to these very high energy Cosmic Rays. At the centre of some of the galaxies are enormous black holes. Powerful magnetic fields can eject matter from these galaxies. These very high energy Cosmic Rays are possible from very high energy sources such as Quasars or Gamma Ray Bursts. Particles from such sources can travel with high energy. Lighter particles like helium atoms are the main constituents of the low energy Cosmic Rays. For high energy Cosmic Rays, it may be possible to have particles with higher mass. These can travel at lower velocity, yet can carry high energy. But when these heavy particles travelling at lower velocity hits the (microwave) back ground photon, the nuclei will split into heavy nuclei + photon ➔ proton + neutron; and neutron ➔ proton + electron.

At the end one would detect protons, but not any heavy nuclei. Thus the nature of the high energy Cosmic Rays remains unexplained

All these calculations are based on the assumption that laws of physics, which describes the exchange of energy when two particles collide, are the same, irrespective of their velocity. But it may be possible that such an assumption is not strictly true and Cosmic Ray particles travelling with a very high velocity, when interacting with a back ground photon, perhaps follows a different rule; it bounces off like a billiard ball, with little loss of energy. Hence there is a big effort trying to understand the nature of very high energy Cosmic Rays

Cosmic Ray Detector Arrays

If the encounters of high energy Cosmic Rays are so sparse, one possible way to detect these would be to build an array of detectors spanning over a large area. Some of the early detector arrays for Cosmic Ray Air Shower were built in the Antarctic. The reason for building in the South Pole is the far away (point) sources rotate by 360° every 24 hours, making the analysis easier. University of Leeds built one of the earlier detector arrays in North Yorkshire spanning an area of over 12 square kilometres. *AMANDA*:



High energy Cosmic Ray particles encountering the Earth, vertical graph indicates number and horizontal the energy

Antarctic Muon and Neutrino Detector Array

It consists of a series of photo multipliers suspended from long wire into Antarctic ice. Sub-atomic particles like Muons and Neutrinos produced by Cosmic Rays can travel though the atmosphere without any interaction, but occasionally, these interact with water or ice and give off a flash of light, detected by these Detectors.

Another large detector array has just become operational. It is the Pierre Auger Observatory in Argentina, in the southern hemisphere and there will be one similar in the northern hemisphere. The grid in Argentina is now operating with 1200 detectors. Eventually there will be 1600 water Cerenkov detectors and 3 fluorescence light detectors spread over 3000km^2. The space between the detectors is about 1.5km, each detector will hold about 11-12 tons of pure water in plastic tanks. All the detectors will be interconnected so as to trace the path of incoming high energy Cosmic Rays. This set up is expected to detect about 30 cosmic ray events a year in the energies above 10^{20}eV, and a large numbers of lower-energy events.

When a Cosmic Ray Air Shower collides with air molecules, it creates fluorescent glows. These can be detected in clear moonless nights by a collection of detectors; which can cover about 360° of the sky and hence called Fly's eye detectors. The more particles in the shower, the higher the energy and hence higher the detected light. These will be also used in the Pierre Auger Observatory in the form of a sub-grid with Cerenkov detectors. These fluorescent detectors can measure cosmic ray showers in more details, but these work only on dark nights. Cerenkov detectors on the other hand works round the clock and therefore can detect more events. So the combination of these two detectors will make it a powerful Cosmic Ray observatory.

It seems the Earth is continuously bombarded with radiation from the Solar and the extra-solar sources. The nature of the radiation is not fully understood, but the new generation of observatories are expected to throw some light on these radiations. Despite the high energy of this radiation, it does not cause much harm on the life on Earth. Earth's magnetic field prevents much of the radiation reaching the Earth's atmosphere. Surrounding the Earth there is a zone of harmful high energy particles. This is the Van Allen belt and is discussed on Page 2 in *Earth's Magnetism, Solar Radiation and Aurora*.

Astronomy with a Satellite Dish

by Mark Edwards

These days we see satellite dishes everywhere, staring blankly into space from every street, all looking the same way as if expecting the imminent arrival of some alien visitor. Little do those who watch Sky TV with them realise that the alien visitor is already here and its broadcasts hide deep beneath the news of the latest exploits of David Beckham. These though are not the broadcasts of little green men, but the natural emissions of that other sky. . .

The Radio Sky

All bodies at temperatures above absolute zero (-273.15˚C or 0˚K) radiate energy in the form of electromagnetic waves. The peak frequency of this blackbody radiation depends upon the temperature of the body - the higher the temperature, the higher the frequency. For everday objects at room temperature the peak is in the infra-red part of the spectrum, wheareas for the Sun and other stars their temperature is high enough for it to be in the visible.

The peak of the radiation might be in the visible, but the radiation itself is emitted over a broad range of frequencies extending from X-rays through the visible into radio frequencies. A star's brightness though, is about a billion times less in the radio than in the visible, making them all but invisible in the radio sky. If the radio sky is not full of stars, what is it full of?

There are other ways of generating radio waves. One way is by the thermal motion of free electrons in an ionised gas. When these electrons are deflected in their passage near a proton they radiate radio waves (so called free-free emission) whose brightness is largely independent of frequency, only declining at very low frequencies.

Another way is non-thermal in origin. This is by the synchrotron mechanism, where electrons spiralling around magnetic fields radiate electromagnetic waves, whose frequency is dependent on the energy of the electrons. The greater their energy, the higher the frequency. As there tend to be fewer high energy electrons in the interstellar medium, the spectrum of synchrotron emission tends to peak at radio frequencies and to tail off with increase in frequency toward the visible. This is just the reverse of the spectrum of thermal sources and makes such non-thermal sources dominate the radio sky.

The above three mechanisms produce broadband radio sources, ie. their radiation is spread over a large range of frequencies, but there is another mechanism that is very important to radio observations of our galaxy. This is the line emission from gas clouds contained within it, the brightest of which is produced by neutral hydrogen at a frequency of 1420Mz (a wavelength of 21cm).

The universe then is awash with radio waves, but can we detect them here on Earth?

The Radio Window

To try to answer this question, we first have to look at our observing position. Unfortunately for radio astronomy (but fortunate for ourselves) we live in an environment that does its best to stop radiation of all types from space hitting us. This includes radio waves. At low frequencies (below about 30MHz), the ionosphere reflects and absorbs the incoming radio waves whereas at high frequencies (above about 30GHz) the atmosphere takes over the role.

The region in between these limits is know as the "radio window" through which we can see the universe. However, this part of the radio spectrum is also the most used by man for communications and broadcasting, including of course direct broadcasting from satellites.

This is convenient for us, as a satellite dish naturally comes equipped with a receiver that operates at 10.7 to 12.7 GHz and consequently will allow us to look through the radio window to the universe beyond, but is it sensitive enough and is the dish is large enough, or do we need a dish the size of the Lovell Telescope? As the Americans would say we need to *"Do the math"*!

Flux Density and Temperature

Radio astronomers do not use stellar magnitudes to measure the brightness of an object, instead they use the flux density of the radiation received from the object. Flux density is a measure of the power received per unit area of antenna, measured in a unit frequency band. The standard unit of flux density is the Jansky (Jy), named after the first radio astronomer Karl Jansky and it has the amazingly small value of:-

$$1Jy = 10^{-26}\ Wm^{-2}\ Hz^{-1}$$

It seems impossible to detect such a small amount of radiation, but incredibly when the radiowaves are collected by an antenna they raise its temperature by a tiny amount given by:-

$$T = \frac{S \times A}{2k} \times 10^{-26} {}^\circ K$$

Where S = Flux density of source (Jy)
A = Area of the antenna (sq m)
k = Boltzmann's constant = 1.38 x 10^{-23} $J°K^{-1}$

Luckily as Bolzmann's constant is equally small, inserting the value of k gives the more promising formula:-

$$T = \frac{S \times A}{2760} {}^\circ K$$

Looking more closely at this formula we can see that if S increases, ie. if we point the antenna at a brighter source, the antenna's temperature T will increase. Similarly if we increase the area of the antenna while looking at the same source, T will also increase.

Now if we use the example of a typical satellite dish of diameter 60cm, its area A = 0.28 sq m, so

$$T = \frac{S}{9760} {}^\circ K$$

Can this small temperature change be detected by the receiver attached to the dish?

Receiver Sensitivity

The sensitivity of a radio receiver is measured in terms of the smallest change in noise temperature that can be detected by it. This temperature change is given by:-

$$\Delta T = \frac{Tsys}{\sqrt{B \times t}} {}^\circ K$$

Where $Tsys$ = System noise temperature (K)
B = Receiver bandwidth (Hz)
t = Integration time (s)
and $Tsys$ = Antenna temperature (Ta) + Receiver noise temperature (Trt)

Looking more closely at this equation, the position in it of the receiver bandwidth (B) might look a little strange, but in essence, the larger the receiver's bandwidth the more power we let into the receiver from the source (at least for broadband sources) and so the weaker the sources we can detect.

Similarly, the longer the time (t) over which we average the receiver's output, the better will we have an idea of the receiver's change in output for a given change of received noise power. This is equivalent to stacking more optical images to reduce the noise in the image and hence see more of its finer details.

Finally, for high sensitivity, the System noise temperature (Tsys) should be minimised. Tsys is made up of two components, the first of these (the Antenna temperature, Ta) is not the antenna's physical temperature, but the temperature of the sky to which it is pointing. This temperature varies with direction and frequency, dropping to a minimum of about 6K between 1 and 10GHz where it is due in part to the 2.7°K Cosmic Microwave Background and in part to the Milky Way's own synchrotron emission.

The second component to Tsys is the Receiver noise tempereture (Trt) and as with Ta does not represent the physical temperature of the receiver, but is a measure of the electronic noise generated within the receiver itself. Within the electronics industry it is more usual to quote an receiver's noise figure (F) rather than temperature, where:-

$$F = 1 + \frac{Trt}{To}$$

and To = standard room temperature = 290° K, so:-

Trt = 290 x (F -1)°K

to complicate the issue, F is usually quoted in decibels (dB), where:-

Fbd = 10 log F

so substituting in the above equation gives:-

$$Trt = 290 \times (10^{\frac{Fdb}{10}} - 1) {}^\circ K$$

Modern satellite receivers (LNBs - Low Noise Blocks) have incredibly low noise figures and ones with a noise figure of 0.3 dB are readily available for a few pounds. From the above equation these have a Trt = 21 K

To give you an idea of how incredible this is, back in the 1970s such a low noise temperature was only atainable with such exotic devices as liquid nitrogen cooled paramps and masers!

Adding this value of Trt to a Ta of 6 K gives a total system temperature of:-

$Tsys$ = 21 + 6 = 27 K

In practice the system temperature will be probably be higher than this as there are other factors to consider, including what is called dish spillover. This is caused by the LNB being able to see past the dish at the hot ground. As the ground is a blackbody radiator at ~290K this can make a considerable difference to Tsys and it is important that the LNB is designed to match the dish being used.

With this in mind and using typical values of a receiver bandwith (B) of 10MHz and an integration time (t) of 1 minute gives a minimum detectable temperature of:-

$$\Delta T = \frac{27}{\sqrt{10000000 \times 60}} = 0.0011 {}^\circ K$$

giving a minimum detectable flux density of

S = 9760 x 0.0011 = 11 Jy

This is very much a theoretical minimum as in practice there are numerous inefficiencies that will increase its value, but even if those amount to 100%, this looks a very promising value.

So do any sources in the radio sky exist which are at least as bright as 11Jy?

Radio sources

Suprisingly, at a frequencies between 10.7 and 12.7 GHz there are at least ten discreet sources, in order of decreasing brightness:-

Source	Flux Density(Jy)
Sun	5,000,000
Moon	100,000
Cassiopeia A	700
M1	600
M42	500
Cygnus A	100
Jupiter	70
M31	60
3C273	48
M87	40

This list looks very strange.

Although we are familiar with the brightest two sources, the **Sun** and **Moon**, the next brightest source is a surprise as it is not a planet, as in the visible sky, but **Cassiopeia A**, a rather faint supernova remnant. Lying 3.4 kpc away in an obscured region of the Milky Way its source star exploded unnoticed in about 1667. As it is the youngest supernova remnant in the Milky Way it is a powerful source of synchrotron radiation.

Continuing down the list:-

M1 The Crab Nebula a supernova remnant 2 kp away, created in an explosion in 1054 and leaving behind a pulsar rotating 30 times a second. Although the pulsed emissions are too weak for our dish to detect, the background synchrotron emission from the nebula is much brighter and should be detectable.

M42 The Orion Nebula an ionised gas cloud (ionised by the young stars at its core) is a strong source of free-free emission.

Cygnus A is remarkable, as optically it is a very faint 15th. magnitude galaxy, 211 Mpc away. What makes so it special is that it contains a very active supermassive black hole emitting two jets of relativistic particles, when these jets hit the inter-galactic medium they emit copious quantities of synchrotron radiation.

Jupiter At these high frequencies the radiation from Jupiter is dominated by its thermal blackbody radiation, not by its non-thermal synchrotron emission so prevelant at low frequencies.

M31 The Andromeda Galaxy is a very bright 3.5 magnitude galaxy, 700 kpc from the Earth and also a source of radio waves.

3C273 is another remarkable object as it is the most powerful quasar in the sky. Optically it is a faint 12.8 magnitude point of light, 640 Mpc away from the Earth, but again emitting a powerful and variable jet. The jet is so powerful that its synchrotron emission extends in to the visible.

M87 A 8.6 magnitude galaxy, 17 Mpc away at the heart of the Virgo cluster of galaxies and also emitting a visible jet.

So it looks as though we can indeed do some astronomy with a satellite dish, but how can we do our observations in practice?

Making observations

One way would be to point the dish at the sky at a certain elevation and let the rotation of the Earth scan across it while measuring the amplitude of the receiver's noise output. As a source passed in front of the dish, the noise output would increase and after many scans a map of the sky could be produced from the measurements. This was the way the first surveys of the sky were produced, but although simple, it suffers from two major problems.

The first is that of gain stablity. Any changes in the gain of the receiver due to temperature, etc. will cause the noise output of the receiver to change as though a source had been detected. Secondly, any interference will also cause a change in receiver output and given that the receiver is operating in the TV satellite band, there are a lot of interfering sources! Idealy what is required is a method that would allow the efects of gain fluctuations and interference to be minimised, while allowing the positive identification of a celestial radio source to be made.

The Dicke Receiver

In 1946 R. H. Dicke introduced the idea of a switched receiver to minimise the effects of gain variations. In this type of receiver the input is connected alternately between the antenna and a comparison load and the measurements are taken from the difference between the corresponding receiver outputs. However, as the gain variations are minimised if the comparison load is at the same temperature as the sky, to make full use of the Dicke receiver would require the load to be cooled to 6°K.

Liquid helium is not that easy to handle! but there is a practical alternative and that is to use the sky itself for the comparison. All we need to do is to place two LNBs at the focus of the dish, one pointed in the direction of interest, the other towards a region of sky devoid of sources. Handily, such "dual focus" LNBs are readily available. When mounted at the focus of a dish they are designed to look at two satellites separated by 6 degrees, which are then selected by a signal sent to the LNB up the cable from the set-top box.

Using such an arrangement and letting a source drift first in front of one LNB then the other should produce an easily identifyable "S" shaped output from our receiver, as first one LNB then the other receives more noise.

The Interferometer

Although the Dicke receiver minimises the effects of gain variations, another technique is required to minimise the effects of interference. This technique is to use an interferometer. A radio interferometer uses two (or more) dishes whose output is combined in such a way that only correlated noise arriving at the dishes produces an output in the receiver. If those dishes are far enough apart they will not suffer the same interference and will not produce a correlated output.

Another effect of using an interferometer is that as the Earth rotates the distance between a radio source and each dish changes. Sometimes the difference in the paths that the radio waves take to each dish is a multiple of a wavelength and the waves reinforce each other and sometimes it is an odd number of half wavelengths and they destroy one another, resulting in the receiver output fluctuating as the Earth rotates.

These fluctuations (or fringes) vary at a predictable rate depending on the position of the source in the sky and allow particular sources to be identified. A side effect is that TV satellites by their synchronous nature remain fixed in position above the dishes and their interfering signals do not produce fringes. Similarly any receiver gain fluctuations just affect the amplitude of the fringes, but do not produce fringes in their own right.

Resolving Power

Interferometers are not just useful in locating radio sources, they can also be used to measure their size and structure with resolutions unobtainable by a single small dish.

The resolution of a single circular dish, ie. its beamwidth, is given by:-

$$\theta = \frac{1.2\lambda}{D} radians$$

where λ = observing wavelength (m)
D = diameter of dish (m)

Substituting values for a dish of diameter D = 60 cm and an observing wavelength of 2.5cm (corresponding to a frequency of 12GHz) gives:-

$$\theta = \frac{1.2 \times 0.025}{0.6} = 0.05 radians = 3^\circ$$

This is not very useful compared to the resolving power of an optical telescope. However, the resolving power of a two dish interferometer is given by:-

$$\theta = \frac{\lambda}{2L} radians$$

where λ = observing wavelngth (m)
L = separation of dishes (m)
and we can make L as large as we like!

As an example, if we separate the dishes by only 2.5 m:-

$$\theta = \frac{0.025}{2 \times 2.5} = 0.005 radians = 0.3^\circ$$

which is sufficient to start to resolve the Sun. Increase the separation to 10m and the Cassiopeia A supernova remnant, whose diameter is 5 arc minutes, can be resolved.

The interferometer seems then to be the ideal instrument, but to make one with two satellite dishes does introduce a number of practical problems. The main problem is to get the two LNBs to operate on the same frequency. To obtain fringes they have to be on exactly the same frequency, to within a fraction of a cycle for the duration of the observations.

Now a standard LNB contains an oscillator that is used to change the frequency of the received radiowaves to a lower one for onward transmission down the cable to the set-top box. Unfortunately this oscillator free runs so there is no chance of its frequency being anywhere near that of another LNB.

One solution to this problem is to disable the oscillators completely and instead send the amplified signals at their original frequency down cables to a third LNB. This third LNB combines the two signals and performs the usual frequency conversion. This allows observations to be made, but having to send microwaves over cables (which incurs great losses) restricts the separation of the dishes to a few metres.

There is, however, a class of LNBs that instead of using a free running oscillator to define the receiving frequency, uses an oscillator locked to an external 10 MHz source. These would be ideal as the same 10MHz reference could be sent to both LNBs and their low frequency outputs correlated with no modifications to the LNBs.

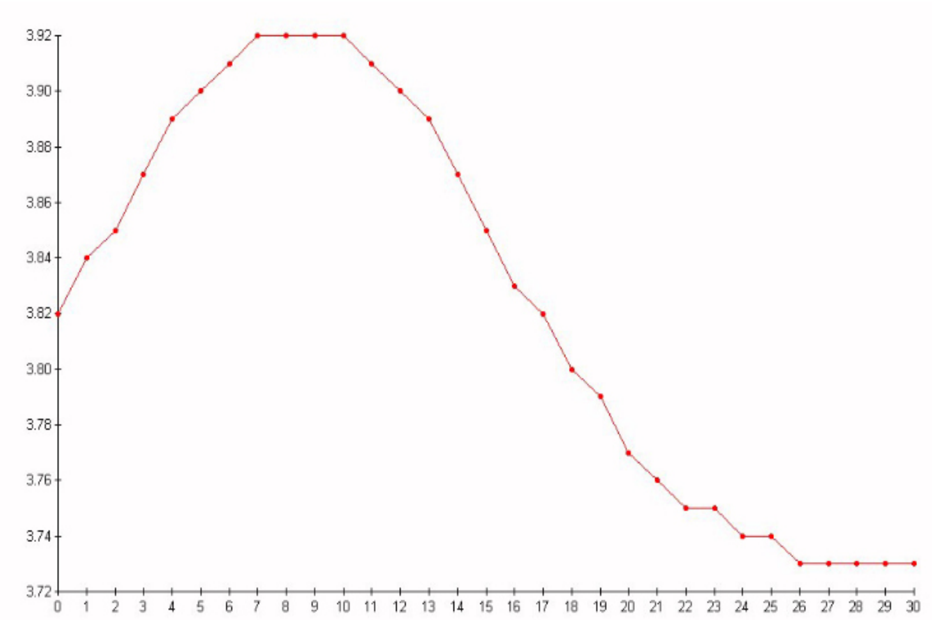
The Possibilities

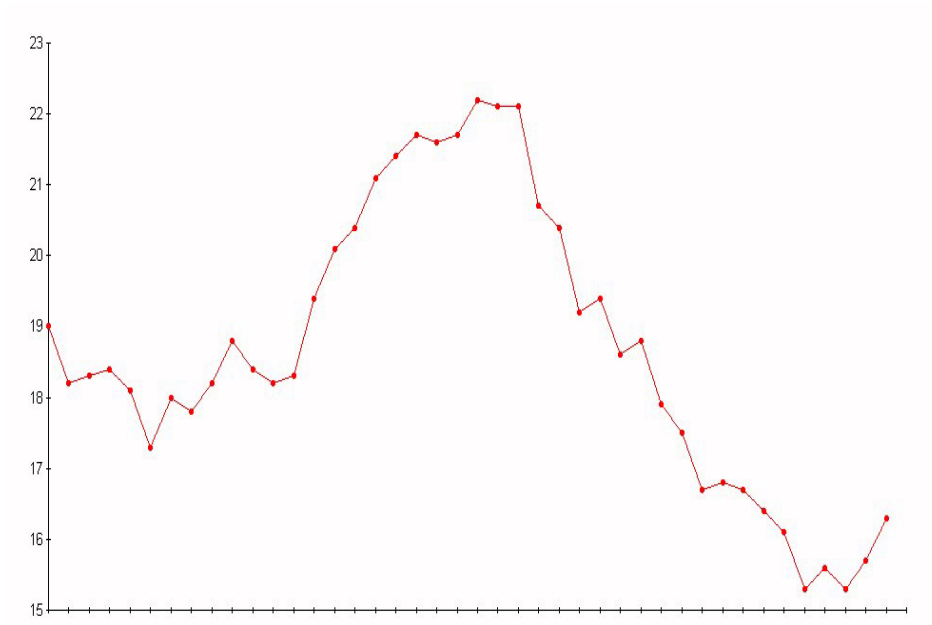
Having made an interferometer, why stop at a baseline of 10m? If the separation of the dishes can be increased to 2.5km, the interferometer would have a resolution of 1 arc second, equivalent to a 6″ optical telescope! All that needs to be done is to lock the two receivers to a single external source and to combine their outputs.

At professional observatories, the signal to lock the receivers is sent out from a central point over a radio or optical link and the receivers' output is returned the same way. For an amateur this might not be possible, but there are ways to achieve the same effect with a bit of lateral thinking.

If a local radio or TV transmitter can be received at both sites its signals can be used to lock the receivers, it could even be possible to use the satellite TV broadcasts themselves to do this. Whereas, with the wide availability of the internet and GPS, it should be possible to digitise the receivers' output, timestamp it with GPS time and then store it on a PC to be combined at a later date or sent over the internet to be combined in real time.

The possibilities are endless and I have already aquired a couple of dishes, so I'll let you know how I get on!. . .





Following on from this radio astronomy article, a friend of mine has given me some LNBs to play with. So today I've been making a few prilimary observations with one of my 60cm dishes and these are the results. They were taken by just pointing the dish to the sky and letting the Sun or Moon drift through the beam. The Sun (Top) is so powerful that you get good signal to noise and a nice peak. The Moon, (Bottom), because it has the same apparent size as the Sun but is at 200K rather than 6000K, gives a peak 30 times smaller, so the graph is somewhat noisy. The dish at the moment is impossible to point, so I'm going to have another go at the Moon when I can see where it is on the dish!

So, you see I wasn't joking, you **can** observe with a satellite dish! and you can sit in inside in the warm to do it. . .