Lecture Notes
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DECAMETRIC RADIO ASTRONOMY

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Decametric, in this case, refers to the frequency range of about 10 to 100 MHz or 30 to 3 meters in wavelength. For ground based radio astronomy the low frequency limit is determined by the ionosphere. Depending on the time of day and year, the earth's ionosphere is completely opaque to radiation below 2 to 10 MHz, and just above the cutoff only sources very near the zenith are visible. The ionosphere also allows the propagation of man-made signals below about 30 MHz from distant points on the earth which interfere with radio observations. The high frequency limit chosen here is an arbitrary one. One hundred megahertz is roughly where dish type instruments become feasible, and many radio sources begin to change their observed characteristics.

One of the biggest problems in low frequency astronomy is obtaining high resolution. At 30 MHz, for instance, a 10 arc minute beamwidth requires a 3.5 km aperture. Obviously a filled aperture or reflector of this size is impractical, so unfilled arrays of simple elements such as dipoles are employed to attain resolutions comparable to dishes at higher frequencies. A 3 km array is about the practical limit at decametric wavelengths. Most arrays of this size have been transit instruments with their beams moved manually in declination. As a consequence, low frequency observations have been slow and laborious. Notable exceptions to this rule are the Culgoora array presently in operation and the new Clark Lake instrument now under construction.

Unlike the case of centimetric instruments, the quest for low system temperatures very quickly reaches a dead end below 100 MHz because the entire sky radiates with a brightness temperature of from 1000 °K at 100 MHz to over

10^5 °K at 10 MHz, and, hence, dominates the output of a radio receiver. These high brightness temperatures are the result of synchrotron radiation in the galaxy which is a non-thermal mechanism, so they are not direct measures of the interstellar medium temperatures.

In addition to reflecting radiation below its cutoff frequency, the ionosphere produces phase gradients and irregularities in the wave fronts of radiation to which it is relatively transparent. These effects are perceived as pointing errors in the beam of a radio telescope and as amplitude and phase scintillations of radio sources. Average pointing errors of 10 and 0.4 arc minutes at 20 and 100 MHz, respectively, at a zenith angle of 45° are due to the spherical shape of the ionosphere. Amplitude scintillations of as much as 100% are not uncommon at 20 MHz.

Source confusion takes on a slightly different character with unfilled arrays commonly used at long wavelengths. With filled apertures such as dishes, the confusion problem is mainly that of more than one weak source in the main beam at a time. Unfilled arrays, on the other hand, have relatively high sidelobes (responses in directions other than the main beam), and in many cases the sidelobe responses cause more confusion than multiple sources in the main beam. The design of an array generally tries to balance sensitivity (proportional to collecting area), main beam confusion (proportional to beam solid angle), sidelobes (roughly inversely proportional to the array filling factor), and cost (proportional to filling factor and aperture).

If one had to characterize decametric radio sources in a single phrase, one would probably say they are mainly non-thermal. By this we mean that the significant radiation mechanisms are not electron-ion collisions in an ionized medium such as an HII region. The most notable exception to this rule is the million degree solar corona. This is not to say that HII regions do not radiate at low frequencies, but since thermal radiative flux is proportional to frequency squared it is much weaker than non-thermal radiation which tends to be stronger at low frequencies. Below is a brief description of some of the stronger types of radio sources at long wavelengths.

Galactic Background

Synchrotron radiation from high energy electrons in the general magnetic field in the Galaxy produces a high sky brightness at low frequencies. This radiation is strongest in the direction of the galactic plane, particularly the galactic center, but there is still significant radiation at the galactic pole. The brightness temperature of the galactic center is about 6×10^3 °K at 100 MHz and 2×10^5 °K at 20 MHz, and the ratio of the center to pole temperatures is roughly 10 to 1 at these frequencies. This radiation is considerably more concentrated toward the plane above 100 MHz.

Below 30 MHz the multitude of HII regions in the galaxy become important not because of their radiation but because of their absorption of the synchrotron radiation. At 20 MHz an optical depth of one would be reached at 5 kpc if the average electron density along the line of sight were 0.4 cm^{-3}, assuming the ionized medium is at the temperature of a typical HII region, 10^4 °K. This is an entirely reasonable average electron density in the galactic plane, so some of the synchrotron radiation should be absorbed in the interstellar medium. This is, in fact, observed as a very narrow "dark" band along the galactic equator a few degrees wide. It is "dark" because the HII region temperature of 10^4 °K is much less than the 2×10^5 °K of the background radiation.

Supernova Remnants

Except for the sun the first and fourth strongest (in apparent flux density) discrete radio sources in the sky are supernova remnants, Cassiopeia A and Taurus A (the Crab Nebula). These too are mainly synchrotron emitters with a flux density spectrum roughly proportional to $f^{-0.5}$. Cas A has a flux density at 30 MHz of about 4×10^{-22} watts meter^{-2} Hz^{-1} or 4×10^{4} flux units. It is easily observable with a simple two dipole interferometer. A typical research instrument would have a sensitivity limit of about 1 flux unit which gives a dynamic range of over 4 orders of magnitude.

As long as a supernova is optically thin its radio spectrum depends on the energy distribution of relativistic electrons and the strength of the magnetic field threading through it. If the electron energy spectrum can be described by a power law

$$N(E)\,dE = KE^{-\gamma}\,dE$$

then the radio flux density spectrum of the SNR will be given by

$$S(\lambda) \propto \lambda^{\frac{\gamma-1}{2}} .$$

In the case of Cas A

$$(\gamma-1)/2 \simeq .8$$

so

$$\gamma = 2.6 .$$

If the magnetic field is weaker, only higher energy electrons will radiate and a little algebra would show that at a given wavelength the flux density goes as

$$S_{\lambda}(H) \propto H^{(\gamma+1)/2} .$$

Typical magnetic fields in SNR's around 10^{-3} gauss with electron densities of 10^{-6} to 10^{-4} cm^{-3} with energies greater than 10^{7} ev.

Around 30 MHz, SNR's become optically thick in terms of synchrotron radiation, and they begin to show a turnover in their spectrum at lower frequencies.

Quasars and Galaxies

This subject will be treated in much better detail by Drs. Fomalont and Shostak, so it will suffice to say here that these objects run a very close second to SNR's in terms of apparent strength at low frequencies even though they are at much greater distances. Their spectra are very similar to that predicted for synchrotron radiation, but they push this mechanism to its limit to explain the high radiation energy densities in these objects. As better low frequency data becomes available, it will be interesting to see where the spectrum turnover occurs for the larger angular diameter objects. Those which have been found to have angular sizes below one arc second become optically thick at centimeter wavelengths.

Pulsars

The peak flux density of most pulsars occurs near 100 MHz and drops off rapidly above 1500 MHz and below 70 MHz. The high frequency fall off is probably intrinsic to the pulsars, but the cause of the low frequency decrease is not firmly established because of the paucity of measurements at that end of the spectrum.

Because of the ionized interstellar medium between a pulsar and the observer, the pulses arrive later at low frequencies. The arrival time difference of a pulse at two frequencies is given by

$$\Delta T = 4.1 \times 10^{3} D \left[\frac{1}{\nu_2^2} - \frac{1}{\nu_1^2}\right] \text{ seconds}$$

where D is the dispersion measure,

$$D = \int N_e \, d\ell \text{ cm}^{-3} \text{ pc}$$

and ν_1 and ν_2 are in MHz. If $\nu_1 = \infty$ and $\nu_2 = 30$ MHz with a typical dispersion measure of 30 cm^{-3} pc

$$\Delta T = 137 \text{ seconds.}$$

Because of the huge pulse time-dispersion at low frequencies, very narrow receiver bandwidths must be employed to prevent smearing of the pulse time s-ructure. This makes pulse detection difficult because of the resulting low sensitivity. Also, multipath scattering in the interstellar medium, which is particularly strong at long wavelengths, tends to broaden the pulse in time to the point where the instantaneous flux is quite low.

The Sun

Below 100 MHz the active sun is orders of magnitude stronger than Cas A and, in fact, observations of anything other than the sun can be impossible during the day when a solar noise storm is in progress.

At decametric wavelengths most radio emission from the sun which is variable over periods of hours or less results from high energy protons and electrons moving through the solar atmosphere, while radiation from the quiet sun, which is essentially non-varying, is due to thermal emission from the 10^6 °K solar corona. At a given frequency the thermal emission comes from the height in the corona where the electron density is just low enough to allow radiation at this frequency to escape. For this reason 100 MHz radiation originates from a lower level in the corona (about 0.1 solar radii from the sun's surface) than 20 MHz radiation which comes from plasma at least 0.8 radii above the photosphere. Because of this, the kinetic temperature of the corona can be measured at different levels by observing it at different wavelengths. At decametric wavelengths the sun appears elliptical in shape which is probably due to an ellipsoidal distribution of electron density.

Solar radio bursts are much more complex than the quiet sun and are, therefore, not as well understood. Burst radiation at meter and decameter wavelengths generally falls into two categories; synchrotron and plasma-oscillation radiation. Synchrotron radiation requires the presence of a magnetic field, which is usually associated with an active region on the sun, and high energy electrons ejected from a disturbance near the photosphere. This type of radiation usually extends over several frequency octaves simultaneously and may last for many minutes to a day or more. Regions of synchrotron emission are either stationary or move slowly in the solar atmosphere.

Plasma oscillations, on the other hand, are excited by fast-moving streams of particles ejected from an instability in the magnetic field over a disturbed region. Radio radiation is produced by the scattering of plasma oscillations by inhomogeneities in the solar atmosphere, and the frequency of the radiation is confined to a rather narrow band near the plasma frequency associated with the electron density in the volume around the ejected particles. As a consequence, the metric and decametric radiation from a burst of particles starts at high frequencies (> 100 MHz) and drifts toward low frequencies as the stream moves higher in the corona and into lower electron densities. The frequency-drift rate depends on the speed of the particle stream, and the two most common rates are about 0.1 MHz/sec and 20 MHz/sec associated with particle speeds of 10^3 and 10^5 km/sec or 0.0006 and 0.06 solar radii/second, respectively.

Observations of the movement and frequency drift of solar bursts have been made with one-dimensional decametric and metric instruments and two-dimensional studies have been made at 80 MHz with the Culgoora array. Both have led to the picture of solar bursts outlined above.

Below are a couple of references to books which I find particularly useful in my work in radio astronomy. Kraus leans heavily on instrumentation, but has a couple of useful general astronomy chapters. Shklovsky is an old book but still a very useful one in terms of radiation mechanisms. The article by Reber is a classic which, if you have not read it, I strongly recommend for its historical interest. There are other radio astronomy articles in this same IRE volume .

Kraus, J. D., 1966, "Radio Astronomy", McGraw-Hill, New York.

Shklovsky, I. S., 1960, "Cosmic Radio Waves", Harvard Univ. Press, Cambridge, Mass.

Reber, G., 1958, Proc. IRE, 46, 15.

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