NATIONAL RADIO ASTRONOMY OBSERVATORY

Lecture Notes
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THE RADIO SUN

Radio radiation from the sun is normally divided into 3 phenomenological categories: quiet sun, slowly varying component, and bursts. Bursts are further divided into five types, each type having very characteristic spectral and temporal properties.

The Quiet Sun

As one might guess, the quiet sun refers to the level of radiation when there are no disturbances on the solar surface. Since the solar atmosphere is an ionized plasma with generally decreasing electron density with altitude, radio waves of a given frequency will only propagate above a certain altitude. The refractive index of a simple plasma is given by

$$n = \sqrt{1 - f_o^2/f^2}$$

where f is the radio frequency and f_o is the critical frequency given by

$$f_o = 9 \times 10^{-3} N^{1/2} \text{ MHz}$$

where N is the electron density in cm^{-3}. Hence, as a radio wave gets closer to the surface of the sun, N gets larger until the refractive index becomes imaginary and the wave is reflected. Also for frequencies above about 100 MHz the optical depth of the plasma due to free-free absorption becomes large near the critical altitude.

From this very simplistic picture one can explain the gross properties of the quiet sun radiation. At long wavelengths all of the observed radiation comes from the 10^6K corona and the sun appears roughly that bright. As the frequency is increased, the critical altitude descends into the chromosphere which is a few x 10^4K and finally into the photosphere at 6000 K. In fact, the temperature profile of the solar atmosphere can be determined by measuring the apparent brightness of the sun over a wide range of frequencies. In practice, the effects of the solar magnetic field and refraction must be taken into account but the principle remains the same.

The Slowly Varying Component

The slowly varying component (S-component) is most prevalent at decimeter wavelengths and is strongly correlated with activity in the photosphere. Because the causative disturbances last for many weeks, the slowly varying component has a 28-day period due to the rotation of the sun.

High resolution maps of the sun show bright areas just above the surface whose area and intensity correlate very well with the S-component which was originally discovered with broad-beam antennas. The bright areas generally appear above the optical phenomena called plages which are, in turn, closely related to sunspots.

The S-component mechanism is thermal and closely related to the quiet sun emission mechanism. An active area on the solar surface enhances the electron density above it which raises the critical altitudes for radio waves. Decimeter radiation which normally originates in the chromosphere has its region of high optical depth pushed up into the hotter corona which results in a higher apparent surface brightness. The highest observed brightnesses are equal to the physical temperature of the corona.

Bursts

The phenomenological categories of solar burst are as complex as galaxy morphology and the Burpee Seed Catalog. Some physical disturbances on the sun show up as different types of burst at different frequencies. Since meter and decameter bursts are the most varied and represent most solar disturbances, only they will be considered here.

Type I bursts were one of the first observed and yet are one of the least understood kinds of solar radiation. Observations at a single frequency show them as a series of many quick bursts of radiation superimposed on a general enhancement of radiation called a noise storm. Individual bursts last only a few seconds while the series of bursts and the noise storm may last for many hours. Type I bursts are generally only observed between 1 and 30 meters, and the radiation is not well correlated over frequency ranges greater than a few megahertz. This radiation appears to come from high in the corona and reaches brightness temperatures much greater than the physical temperature of the corona. Circular polarization can be as high as 100%, and the sense of polarization corresponds to the magnetic field polarity of the associated sunspot group.

Type II, or slow drift bursts, are best characterized by the fact that a sharp rise in solar radiation is seen at a later time at low frequencies than at higher ones. This type of burst is believed to be caused by plasma oscillations being excited by a shock front propagating up through the corona. The frequency of maximum plasma radiation is just above the critical frequency, so as the shock front moves into lower electron densities, the radiation frequency decreases. Drift rates are on the order of a few tenths of MHz/sec which implies shock front motions of about 1000 km/sec.

In many ways type III, or fast drift bursts, are identical to type two bursts except that their duration is much shorter (seconds instead of minutes) and the drift rate is much higher -- on the order of 100 to 500 MHz/sec. It is believed that this type of radiation is excited by partical streams traveling at a few tenths the speed of light. Typical starting frequencies for type II and III bursts are 100 to 500 MHz although type III's can be seen much higher and have been traced to a few tens of kHz with satellites.

Type IV radiation is more of a noise storm than a burst. Like type II and III bursts, the time of onset of enhanced solar radiation is delayed at lower frequencies, but unlike the bursts, it does not die out quickly, so a few minutes after the start of the storm at high frequencies (a few hundred MHz) a relatively smooth continuum radiation can be seen to below 10 MHz which may last for a few tens of minutes to as long as a few days. This type of radiation is pretty well determined to be synchrotron emission from a swarm of relativistic electrons drifting rapidly up through the solar atmosphere. Typical drift velocities are on the order of 1000 to 3000 km/sec, and type II and type IV bursts are often seen together.

Type V bursts are essentially not understood at this time. They follow about 30% of the type III bursts and look like miniature type IV's in the sense of frequency range and duration. Their position and time of onset are very close to those of the associated type III.

For a much more detailed description of solar phenomena, the book "Solar Radio Astronomy" by Kundu is probably one of the best in the field.

1. Below 100 MHz the apparent brightness of the center of the sun is less than the coronal temperature. Why?

2. What effect would the solar magnetic field have on propagation of radio waves? What happens to the critical altitude of different senses of polarization?

3. How can brightness temperatures greater than 2×10^6 K be generated on the sun?

4. Can you guess what the physical connection between type II and IV bursts is?