HIGH RESOLUTION INTERFEROMETRY OF THE SUN AT 3.7 CM WAVELENGTH

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Abstract. Interferometric observations of the Sun at a wavelength $\lambda = 3.7$ cm and an effective angular resolution of $\theta = 7$ or $15^\circ$ are presented. When active regions are observed, circularly polarized radiation is found with an angular size of $\theta \approx 15^\circ$, an effective temperature of $T \approx 5 \times 10^{5}$ K, and 20 to 30% circular polarization. This S-component of solar radio radiation is interpreted in terms of the theory of gyroradiation and gyroresonant absorption. Prior to the onset of a solar flare, an additional S-component is observed with an angular size of $\theta \leq 7^\circ$, an effective temperature of $T \geq 10^{6}$ K, and $90 \pm 10\%$ circular polarization. A small scale, quasi-periodic component of solar radio radiation is also observed to be coming from all over the solar disk; and this component is found to be less than 10% circularly polarized. The angular sizes, $\theta$, and periods, $P$, of this component lie in the ranges $7^\circ \leq \theta \leq 37^\circ$ and $180 \text{s} \leq P \leq 750 \text{s}$. The observed modulation in flux density, $\Delta S$, lies in the range $20 \text{ f.u.} \leq \Delta S \leq 200 \text{ f.u.}$ ($1 \text{ f.u.} = 10^{-26} \text{ Wm}^{-2} \text{ Hz}^{-1}$ or $10^{-23} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ Hz}^{-1}$) and the brightness temperature fluctuations, $\Delta T$, lie in the range $10^{3}$ K $\leq \Delta T \leq 10^{5}$ K. This component of solar radio radiation is thought to be the free-free radiation (bremsstrahlung) of temperature fluctuations associated with velocity oscillations in the chromosphere-corona transition region. High resolution observations of impulsive microwave bursts show that some of the radiation is linearly or circularly polarized, has an angular size $\theta \leq 7^\circ$, and a peak brightness temperature of $T \geq 3 \times 10^{6}$ K. This component of solar radio flares is interpreted in terms of the theory of gyro-synchrotron radiation, and the density of accelerated electrons is found to be greater than $100 \text{ cm}^{-3}$. The size of the emitting region is, however, comparable to that of the feet of magnetic dipoles rather than the region between them. Phase shifts in the interferometer pattern observed during an impulsive burst are interpreted in terms of hydrodynamic waves travelling at a velocity of $7000 \text{ km s}^{-1}$, but further observations are needed to confirm the result.

1. Introduction

Observations of the radio emission of the Sun at wavelengths near 3 cm show a slowly varying S-component which varies on a time scale of days (Denisse, 1948; Pawsey and Yabsley, 1949), and whose emitting regions exist in the vicinity of sunspots and chromospheric plages (Covington, 1949; Dodson, 1954; Swarup, 1961). The angular size of this component was found to be a few minutes of arc (Kundu, 1959; Swarup, 1961) and effective temperatures between $10^{5}$ and $10^{6}$ K were obtained. The radiation was also found to be 20 to 30% circularly polarized (Tanaka and Kakinuma, 1956, 1958, 1962). The observed S-component radiation is thought to be gyroradiation at the gyrofrequency and its harmonics of thermal electrons in dense regions of the corona above sunspots; provided that gyroresonant absorption is taken into account (Stepanov, 1958; Ginzburg and Zheleznyakov, 1959; Kakinuma and Swarup, 1962; Zheleznyakov, 1962).

In this paper we provide observations of the Sun at 3.7 cm wavelength with angular

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resolutions of 15 and 7". When sunspots were observed, radiation was found with an angular size, $\theta \approx 15^\circ$, an effective temperature $T \approx 5 \times 10^5$ K, and 20-30% circular polarization. This component of solar radiation is explainable in terms of the theory of gyroradiation and gyroresonant absorption. Prior to the onset of a solar flare, an additional component was observed with an angular size, $\theta \leq 7^\circ$, an effective temperature, $T \geq 10^6$ K, and a circular polarization of between 90 and 100%. This radiation might be caused by the emergence of new magnetic fields which are thought to trigger solar flares.

Unexpectedly, emission with an angular size less than 15" and an effective temperature, $T$, in the range $10^3$ K $\leq T \leq 10^5$ K was found to come from all over the solar disk, including the north and south poles. The intensity of this small scale, disk component was found to vary quasi-periodically with periods, $P$, in the range $180 \leq P \leq 750$ s; and the radiation was found to be less than 10% circularly polarized. Yudin (1968) has previously reported the detection of similar fluctuations at $\lambda = 3.3$ cm. He measured the difference between the antenna temperature, $T_A$, due to the Sun and the temperature, $T_N$, due to a noise generator to obtain $\Delta T = T_A - T_N \approx 0.01 T_A \approx 10^2$ K for periods in the range $100$ s $\leq P \leq 600$ s. The observations presented in this paper were made with a correlation type interferometer whose component antennas had a collecting area comparable to that of the single antenna used by Yudin. This mode of observing the quasi-periodic emission has the advantages of doubling the effective collecting area, and of electronically differencing out the background signal due to large solar sources. Because the periods and angular size of the detected radio radiation are comparable to those observed for velocity oscillations in the high photosphere and low chromosphere (Leighton et al., 1962), it is suggested that this component of radio emission is the free-free radiation (bremsstrahlung) of temperature fluctuations associated with the velocity oscillations.

Previous observations of the emission of the Sun at wavelengths near 3 cm have also shown impulsive events which are well correlated with solar flares observed in H$\alpha$ and at X-ray wavelengths. The angular size of the impulsive burst at 9.4 GHz has been estimated to be approximately half a minute of arc (Énomé et al., 1969), and these bursts are 40 to 50% circularly polarized (Tanaka and Énomé, 1970). Microwave bursts have been adequately explained as gyrosynchrotron radiation of electrons accelerated during the solar flare (Takakura and Kai, 1966; Takakura, 1967; Ramaty, 1969). In order to account for the observed lack of center-limb variations in intensity, the gyrosynchrotron radiation is proposed to come from nonthermal electrons trapped in a magnetic dipole field (Takakura and Scalise, 1970).

In this paper we also provide observations of impulsive bursts of solar radiation at 3.7 cm wavelength. A small fraction of the impulsive radio radiation is circularly polarized and comes from sources smaller than 7" in size. This emission may be associated with the bright points observed in H$\alpha$ during a flare; and suggests that some impulsive emission may come from the feet of magnetic dipoles. Phase shifts in the observed interferometer pattern during an impulsive burst suggest blinking bright spots or the ejection of plasma at high velocities.