A MODEL OF THE ATMOSPHERE ABOVE A SUNSPOT FROM RADIO OBSERVATIONS


The results of VLA observations of an unusual source of microwave radiation, associated with the sunspot NOAA 7789 on October, 15, 1994, are presented. The fine structure of the source, which is a ring structure in intensity and polarization at frequencies 4.5 and 8.0 GHz, is discussed. It is shown that the features observed can be explained by a thermal cyclotron mechanism if the magnetic field is approximated by a vertical dipole buried under the photosphere, but the spatial distributions of kinetic temperature and electron density in the atmosphere above the sunspot differ considerably from the standard model. A two-dimensional source model (the dependences of the parameters on the height and distance from the center of the sunspot), which fits the observations at the above frequencies, is evolved. The principal physical result is that the data observed are explainable by the presence of an unexpectedly dense cool plasma in the atmosphere over the center of the umbra.

1. INTRODUCTION

The microwave radiation of sunspot-associated sources (the so-called slowly varying component of solar radio emission or s-component) has been studied for more than thirty years. At present, voluminous observational data on the sources induced by magnetic fields of sunspots — frequency spectra, polarization, directivity, etc. (see, for example, [1-16] and references there) — are available. All these data affirm the idea [17-18], suggested in 1962, that the enhanced radiation at centimeter wavelengths appears mainly due to the cyclotron (magneto-bremssstrahlung, gyroresonance) radiation of thermal electrons in the atmosphere of the active region above the sunspot, and the bremsstrahlung mechanism can be efficient at wavelengths shorter than 2-3 cm and longer than 20-30 cm. Naturally, the observed characteristics depend on physical conditions (three-dimensional distribution of the magnetic field, kinetic temperature, and electron density) and the location of the source on the solar disk. The characteristics of the s-component for different models of the source have been calculated in many works (see, for example, [10-28] and references there), and the parameters of the atmosphere over an active region (extrapolated from the optical and UV observations of the photosphere and the chromosphere to the transitional region and lower corona) fit observational radio data rather well.

On the other hand, the relative simplicity of the approximate expressions relating the frequency of the observed radio emission with the magnitude of the magnetic field and the brightness temperature with the kinetic temperature of the source, in the framework of the cyclotron mechanism, allows one to retrieve the physical conditions in the sunspot atmosphere from the observed characteristics. Thus, recording the sunspot-associated microwave radiation provides an easy diagnostics of the solar atmosphere above a sunspot, which is a region not observable by optical methods. Up to now the mentioned diagnostics was applied mainly to the magnetic field [29-30]. Information on the distribution of electron density above a sunspot is not easily derived from data on the s-component. As for the kinetic temperature, it is quite possible to evaluate it from the observed frequency spectrum of the radiation, since the dependence of the brightness temperature on wavelength mimics in some scale (under the assumption of monotonous changing of parameters with height and optically thick gyroresonance layers) the dependence of the kinetic temperature on height.
Fig. 1. Two-dimensional maps of the microwave source, obtained by VLA at frequencies 5.0 and 8.0 GHz in two circular polarizations.

However, at present only models with a homogeneous temperature distribution over the source have been considered, the observed radio brightness distributions being explained by the inhomogeneous distribution of the magnetic field in the plane parallel to the solar surface. In this case peculiar structures like a ring or a horseshoe, as a rule, have been stipulated by the dependence of the optical thickness of gyrososonance layers on the angle between the magnetic field and the line-of-sight (enhanced transparency along the magnetic field) [10, 20, 23]. In this paper VLA data on the microwave source, associated with the sunspot NOAA 7789, October, 15, 1994, at frequencies 4.5 and 8.0 GHz* in two polarizations, as well as results of the model calculations of the cyclotron emission for the homogeneous and inhomogeneous distributions of the kinetic temperature and the electron density over the source, are given. Analysis of various models has shown that the observed data could be explained only by assuming an inhomogeneous distribution over the sunspot, namely the presence of a more dense cool plasma above the center of the umbra than in the surrounding atmosphere.

*Observations were also made at 15 GHz frequency. The results and model calculations taking into account the free-free mechanism are given in the work [31]. The contribution of bremsstrahlung mechanism to the emission at frequencies 4.5 and 8.0 GHz is negligibly small.