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Simulation of the rotation-modulated and satellite-induced radio emissions from brown dwarfs

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Abstract

We simulate the dynamic spectra of the radio emission from a brown dwarf. The emission is produced due to the electron-cyclotron maser instability. Two source models are considered: the emission caused by interaction with a satellite and the emission from a sector of active longitudes. We have found that for the dwarf TVLM 513 the model of an active sector (with a highly tilted magnetic dipole) fits the observations better.

1. Introduction

Recently, a number of late M stars and brown dwarfs were found to be the sources of unexpectedly intense radio emission at the frequencies of a few GHz. In addition to a quiescent component, the emission can include short periodic pulses with almost 100% circular polarization, whose period seems to coincide with the rotation period of the star [1]. These features are untypical for the stellar radio emission and more similar to the emission of the magnetized planets of the Solar System (but with a much higher intensity and a much stronger magnetic field). In particular, the most likely emission mechanism is the electron-cyclotron maser instability. The observations indicate that the magnetic fields should be stable at timescales of at least several months [2]. Analysis of the radio observations allows us to study the magnetic field topology and other parameters of the magnetospheres of brown dwarfs.

2. Model

The aim of this study is to simulate the dynamic spectra of the radio emission from brown dwarfs and compare the results with the observations. We have developed two numerical models similar to the cases observed in the Solar System [3]:

a) Satellite-induced emission (analogous to the Io-Jupiter system). It is assumed that the magnetic field of the brown dwarf is dipole-like and the emission is generated at the magnetic field line passing through the satellite. The orbital period of the satellite depends on the stellar mass and the orbit radius.

b) Emission from a sector of active longitudes (like in the case of the Jovian hectometric radiation). In this model, the magnetic field is dipole-like and the emission is generated at the chosen magnetic field lines within a narrow range of magnetic longitudes.

In both models, we can specify the dipole tilt and offset (relative to the star rotation axis and centre) as well as the inclination of the stellar equator and satellite orbit (relative to the line of sight). The emission is produced due to the electron-cyclotron maser instability; both the loss-cone-driven and shell-driven instabilities are considered. In the simulations, we use the parameters of the M9 dwarf TVLM 513: rotation period $T_{\rm rot} = 1.96$ h, mass $M_* = 0.07 M_\odot$, radius $R_* = 70\,000$ km; the surface magnetic field at the magnetic pole is estimated as $B_0 = 3200$ G.

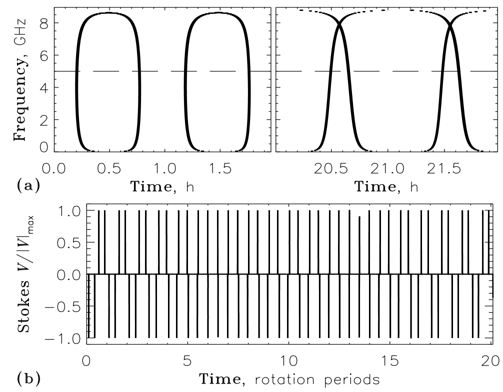

Figure 1: Simulated radio emission for the model with a satellite. a) Two fragments of the dynamic spectrum (Stokes I). b) Light curve (Stokes V) at the frequency of 5 GHz. Dipole tilt $\delta = 45°$. Satellite orbital period $T_{\rm orb} = 20.1 T_{\rm rot}$, orbit radius $R_{\rm orb} = 24.0 R_*$, orbit inclination $i = 0°$. Loss-cone instability is considered.

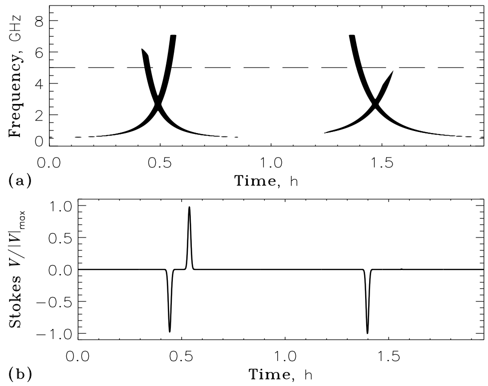

Figure 2: Simulated radio emission from an active sector. a) Dynamic spectrum (Stokes I). b) Light curve (Stokes V) at the frequency of 5 GHz. Dipole tilt $\delta = 60°$, magnetic line number $L = 2$, equatorial plane inclination $i = -20°$. Shell instability is considered.

3. Results

Only a few dynamic spectra (with a rather narrow frequency range) of radio emission from brown dwarfs have been observed to date. Therefore we focus mainly on the emission light curves at a single frequency.

Satellite-induced emission. We consider the case when the satellite orbital period $T_{\rm orb}$ is much longer than the stellar rotation period $T_{\rm rot}$. If the magnetic dipole tilt is relatively small, then the emission pulses occur in series (corresponding to the favourable orbital phases of the satellite) separated by the periods of inactivity. For the larger dipole tilts, we can see, in general, four emission pulses (two with the right polarization and two with the left polarization) per each rotation period, as shown in Fig. 1. In both cases, the intervals between the pulses are not constant. Moreover, the intervals between the consecutive left-polarized pulses vary in antiphase with the intervals between the right-polarized pulses; therefore, the dynamic spectra and light curves for a chosen rotation period look different for the different orbital phases of the satellite.

Emission from an active sector. In this model, the particle acceleration occurs at the boundary of the magnetosphere co-rotation region due to magnetic reconnection. For the brown dwarfs, the co-rotation radius is expected to be rather small [4]; therefore we consider the magnetic field lines with the L-shell numbers of about 2. We also assume that the active field line is the line that crosses the stellar equatorial plane at the maximal distance from the rotation axis. Evidently, the period of the emission pulses is constant and equals the stellar rotation period. At a given frequency, we can observe up to four pulses (two with the right polarization and two with the left polarization) per rotation period. The dipole offset relative to the star centre and the occultation effects can remove some of the pulses. Figure 2 demonstrates the case when the simulated emission light curves are similar to those observed from TVLM 513 in May 2008.

4. Conclusions

Variations of the light curves from period to period in the model with a satellite can fall below the time resolution of the instrument if the radius of the satellite orbit is rather large ($\gtrsim 50R_*$); therefore, it may be difficult to distinguish between the two described models if the observations cover only a few consecutive rotation periods. In the case of TVLM 513, the pulse period and time profiles of the emission have been found to be stable at timescales of days and ever months. Thus the model of satellite-induced emission can be ruled out for this object. Nevertheless, this model can be true for other brown dwarfs.

On the other hand, the model of emission from a sector of active longitudes allows us to explain qualitatively the observed light curves of the emission from TVLM 513. It seems that the magnetic dipole of the dwarf is highly tilted, similar to that of Uranus. Also, the model with the shell-driven instability fits the observations better. Dynamic spectra of the emission with high temporal and spectral resolution are necessary to make more definite conclusions about the source parameters.

Acknowledgements

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