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Pulsating Coherent Radio Emission from Ultracool Dwarfs

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Abstract. We detected periodic bursts of extremely bright, 100% polarized radio emission from two dwarfs at the stellar/substellar boundary. These bursts are conclusively coherent in nature and are produced at the magnetic polar regions by the electron cyclotron maser instability, the same mechanism known to generate planetary coherent radio emission in our solar system. The resulting narrow beams of radiation pass our line of sight as each dwarf rotates, analogous to pulsars. These results point to the electron cyclotron maser instability as a ubiquitous source of coherent radio emission in a wide range of astrophysical objects ranging from planets through to brown dwarfs and low mass stars. The unknown mechanism responsible for pulsar radio emission may also be a related instability.

Key words. Radio continuum: stars – Stars: low mass, brown dwarfs – Stars: activity – Stars: magnetic fields – Stars: rotation – Radiation mechanisms: – non-thermal

1. Introduction

Ultracool dwarfs are characterised by much lower surface temperatures than their higher mass stellar counterparts. This drop in temperature is accompanied by an apparent drop in magnetic activity, as evidenced by the low X-ray and Hα luminosities of ultracool dwarfs. However, a number of ultracool dwarfs have been detected as relatively strong sources of radio emission (Berger et al. 2001; Berger 2002; Burgasser & Putman 2002; Berger 2006; Phan-Bao et al. 2007), suggesting some form of magnetic activity in the atmospheres of these cooler objects. It has been postulated that this anomalous radio emission may be incoherent synchrotron radiation similar to that detected from earlier type stars (Berger et al. 2005; Osten et al. 2006), or alternatively some form of coherent emission (Hallinan et al. 2006). We have used the Very Large Array (VLA) to conduct high sensitivity observations of two ultracool dwarfs, the M9 dwarf TVLM 513-46546 (hereafter TVLM 513) and the M8.5 dwarf LSR J1835+3259 (hereafter

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LSR J1835) which firmly establish the exact nature of this radio emission.

2. Observations

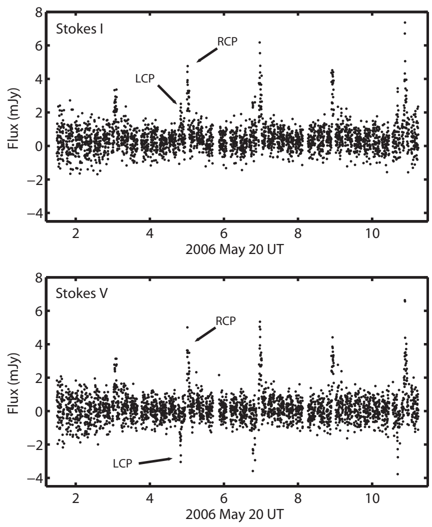

Fig. 1. Light curve of the 8.4 GHz radio emission from TVLM 513. (A) The total intensity (Stokes I) and (B) the circularly polarized (Stokes V) radio emission received at 8.4 GHz from TVLM 513 with a time resolution of 10 seconds, with right circular polarization represented by positive values and left circular polarization represented by negative values. Bursts of both 100% right circularly polarized emission (an example is highlighted as RCP) and 100 left circularly polarized emission (an example is highlighted as LCP) are detected with a periodicity of 1.96 hours.

We observed TVLM 513 for $\sim$ 10 hours at a frequency of 8.4 GHz on May 20 2006 and for $\sim$ 10 hours at a frequency of 4.9 GHz on May 21 2006. The light curve of the 8.4 GHz radio emission, shown in Figure 1, is characterized by periodic (p = 1.96 hours) short bursts of extremely bright, 100% circularly polarized emission. Similar periodic bursts are also present in the 4.9 GHz light curve, confirming the broadband nature of the radio emission. We have directly established that this periodicity corresponds to the rotational period of the dwarf, through I band photometric monitoring observations of TVLM 513 (Figure 2). Therefore, although the bright, polarized bursts appear transient in nature, they are produced by the strong beaming of persistent emission together with the rapid rotation of the dwarf. From the duration of these bursts, it is possible to geometrically constrain the size of the emitting source regions to be $<$ 0.22 times the radius of the dwarf. Using this value, we can establish the brightness temperature of the radio emission to be $> 2.4 \times 10^{11}$ K, which, together with the 100% circular polarization and extremely narrow beaming, provides conclusive confirmation of its coherent nature.

We observed the second ultracool dwarf, LSR J1835, for 10.5 hours on September 18/19 2006. Once again, periodic (p = 2.84 hours) bursts of extremely bright, 100% circularly polarized emission were detected, confirming LSR J1835 to be an analog of TVLM 513. The characteristics of the periodic bursts detected from both dwarfs, which include 100% circular polarization, high brightness temperature and very narrow beaming, are all consistent with coherent emission generated via the electron cyclotron maser instability. We can thus directly derive the required magnetic field strength in the source regions of the 8.4 GHz bursts detected from TVLM 513 and LSR J1835 to be $\sim$ 3 kilogauss. These values are in agreement with the recent direct measurements of magnetic field strengths for ultracool dwarfs (Reiners & Basri 2007).

3. Discussion

The electron cyclotron maser emission is generated in the polar regions of a large-scale magnetic field. Plasma can escape along open field lines over the magnetic poles, resulting in low plasma density cavities where the electron cyclotron frequency can greatly exceed the plasma frequency. Electrons, accelerated into these density cavities by magnetic field aligned electric fields, conserve magnetic momentum by evolving adiabatically to higher pitch angles forming a shell distribution in velocity space, providing the free energy to power the electron cyclotron maser. Although, the emis-

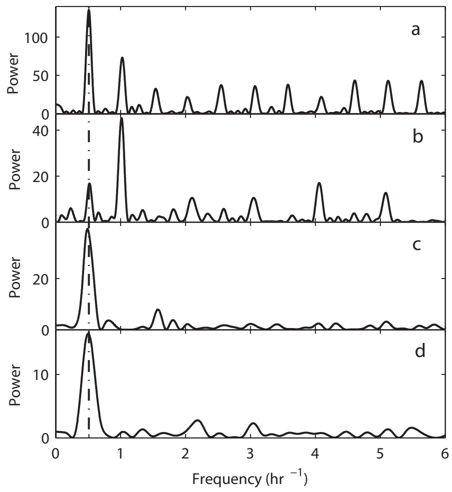

Fig. 2. Lomb-Scargle Periodograms of (a) the 8.4 GHz total intensity radio emission from TVLM 513 obtained on May 20 2006, (b) the 4.9 GHz total intensity radio emission from TVLM 513 obtained on May 21 2006, (c) the 178 I band photometric frames obtained on May 21 2006 with the Vatican Observatory Arizona 1.8m telescope, (d) the 71 I band photometric frames obtained on May 18 2006 with the US Naval Observatory Flagstaff Station 1m telescope. The dashed line corresponds to the putative rotational period of 1.96 hours for TVLM 513. The periodicity present in the radio data is also present in the optical data confirming rotation of the dwarf as the source of this periodicity.We note that the optical periodicity, coupled with the confirmation of very strong magnetic fields for TVLM 513, presents strong evidence for the presence of magnetic spots on the surface of this ultracool dwarf.

sion is intrinsically narrow-banded, the instability can be sustained over a range of heights above the stellar surface producing pseudo-broadband, coherent radio emission. This radio emission is emitted perpendicular to the local magnetic field, with bursts of opposite polarity originating from regions of opposite magnetic polarity, accounting for the detection of both left and right 100% circularly polarized bursts from TVLM 513.

4. Conclusion

We have shown that ultracool dwarfs can generate persistent levels of broadband, coherent electron cyclotron maser emission, which is emitted in narrow beams from the poles of a strong, large-scale ordered magnetic field. These beams of radiation sweep Earth with rotation of the dwarf to produce periodic bursts of 100% circularly polarized radio emission. This result points to the electron cyclotron maser as a ubiquitous source of coherent radio emission from objects with large-scale magnetic fields, including planets, brown dwarfs and low mass stars. This mechanism may also be closely related to the unknown mechanism responsible for pulsar radio emission.

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