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INVESTIGATING MAGNETIC FIELD STRENGTHS AND TOPOLOGIES FOR PULSING ULTRACOOL DWARFS: THE M8.5 DWARF TVLM 513-46546

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Abstract. The detection of both quiescent and flaring nonthermal radio emission from a number of late M-, L-type dwarfs indicates the presence of magnetic activity in the ultracool dwarf domain. What is more, four of those dwarfs show periodic, highly circularly polarized pulsing signatures consistent with electron cyclotron maser emission. The pulsing emission can be used as a powerful diagnostic of magnetic field strengths and topologies of very low-mass stars and brown dwarfs.

Here we present our results from multi-epoch VLA observations of the M8.5 dwarf TVLM 513-46546 which provide evidence of the presence of stable large-scale magnetic fields with kilogaus strengths, as well as broadband dynamic spectra of the individual pulses in the emission of the dwarf obtained using the Arecibo Observatory. We discuss how such observations can be used for mapping the radio coronae of UCDs.

1. INTRODUCTION

Recent VLA observations have found several ultracool dwarfs (Hallinan et al. 2006, 2007, 2008, Antonova et al. 2008) to emit extremely strong, bright and highly circularly polarized beams of radio waves with periodicities, consistent with the respective rotational periods of the dwarfs. The emission was interpreted as coherent electron cyclotron maser (ECM) emission, originating at the polar regions of a large-scale magnetic field.

The observation of pulsed coherent emission from these ultracool dwarfs is in effect, the discovery of a completely new category of radio emitting object and has immense implications for our understanding of both stellar magnetic activity and the dynamo mechanism generating magnetic fields in fully convective stars and brown dwarfs. It is a significant departure from the incoherent gyrosynchrotron emission model generally applied to cool stars and, in fact, has more in common with the coherent radio emission observed from all of the magnetized planets in our solar system.

One such object is the M8.5 dwarf TVLM 513-46546 (TVLM 513). Hallinan et al. (2007) conducted 10 hr observations of TVLM 513 at 4.9 GHz and 8.4 GHz. The dwarf was found to be producing series of short, periodic pulses of 100 % circularly polarized emission. Simultaneous photometric observations confirmed the observed in the radio periodicity to be associated with the rotational period of the dwarf (Lane et al. 2007).

Here, we discuss follow up observations of TVLM 513 taken in June 2007 and May 2008.

2. MAGNETIC FIELD STRENGTH AND TOPOLOGY OF A PULSATING ULTRACOOL DWARF

On 1 June 2007 follow-up observations of TVLM 513 at 8.6 GHz were conducted for 8 hours using the NRAO Very Large Array (VLA)[1] which resulted in the detection of both quiescent emission and periodic pulses with high degree of circular polarization. The Lomb-Scargle periodogram analysis of the time-series confirmed a periodicity of $\approx$ 1.96 hr as is the case for the January 2005 and May 2006 data (Hallinan et al. 2006, 2007).

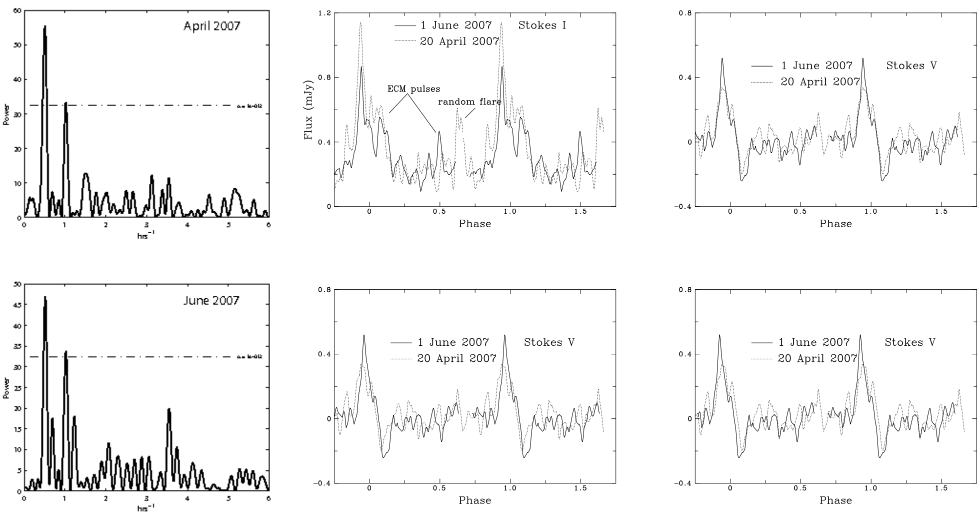

Figure 1: Left: Lomb-Scargle periodograms of the observations of TVLM 513 conducted in April (top) and June 2007 (bottom). The X-axis shows the frequency (hr^{-1}), the Y-axis shows the power. The dot-dashed horizontal lines shows false alarm probability of 10^{-12}. Right: The top panels show the Stokes I and V from June 2007 (solid line) and April 2007 (dotted line) phase folded with a period of 1.95957 hrs from 20 April 2007 00:15 UT. In the bottom panel we show the results for Stokes V where the phase is shifted by $\pm$0.00007 hrs; 1.95950 hrs (left panel) and 1.95964 hrs (right panel). In the top left panel, we label the stable ECM burst region and the random flare event.

[1]The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

Interestingly enough, in April 2007 (i.e. less than 6 weeks prior to our observations), Berger et al. (2008) observed the same dwarf and reported the detection of several brightenings, yet no periodicity. We, however, have reduced these data and can confirm that the periodicity of 1.96 hr is present with high significance (Fig. 1, left). Furthermore, due to the short gap between observations, we were able to phase correlate the data sets from April and June 2007 which confirms a very stable field configuration over this period (Fig. 1, right).

ECM emission is a vital diagnostic tool for remote sensing of the plasma conditions and magnetic field strengths and topologies of ultracool dwarfs. Indeed, in-situ observations in planetary magnetospheres have confirmed that: (i) the emission is generated at the electron cyclotron frequency ($\nu_c \approx 2.8 \times 10^6 B$ Hz) which gives an extremely accurate measurement of the magnetic field strength in the source region; (ii) emission is predominantly in the R-X mode and yields the polarity of the source region; (iii) the narrow beaming allows to constrain both source size (hence brightness temperature) and source location.

The detection of ECM emission at 8.6 GHz from TVLM 513 confirms magnetic field strengths of ≈ 3 kG. Using data taken 42 days apart, we have established to a high degree of accuracy the lack of evolution in the morphology of the periodic light curves, although changes in the structure of the pulses are observable from one rotation to the next. Nevertheless, the overall pulse interval does still occur (within a few minutes) at the same orbital phase which is indicative of a large-scale, stable magnetic field. Aperiodic flaring events are possible, thus in order to distinguish between periodic and random flares, it is essential to do a proper period analysis. Phase connecting both datasets, gives a more accurate period of 1.95957 hours. Ongoing photometric monitoring observations should yield sufficiently accurate rotation period enabling us to phase connect these data to earlier observations of TVLM 513.

3. ARECIBO DYNAMIC SPECTRA

To obtain a broadband dynamic spectra, we observed TVLM 513 over 3 successive nights, using the Wide-band Arecibo Pulsar processor (WAPP) backend of the Arecibo telescope spanning the range of 4300 - 5300 MHz. As a result we can report the detection of pulses on each of the nights and the highest intensity radio emission yet detected from an ultracool dwarf in excess of 20 mJy. A short duration structure in the periodic pulses has yielded brightness temperatures 10^{15} K (Fig. 2). Although a significant variability is present in the amplitude of the periodic pulses, they remain stable in phase and morphology.

There is significant evidence of the presence of double-peaked structure in many of the pulses. Also, the pulses show temporal broadening with increasing frequency (Fig. 2) which is reminiscent of the inverted-V electron precipitation associated with the auroral kilometric radiation detected at high latitudes in the Earth's magnoetosphere (Green et al. 1979). This may prove to be a key signature to electron cyclotron emission from stellar and substellar magnetosheres. However, further Arecibo observations of TVLM 513 as well as other pulsing dwarfs are required to investigate the ubiquity of this phenomena.

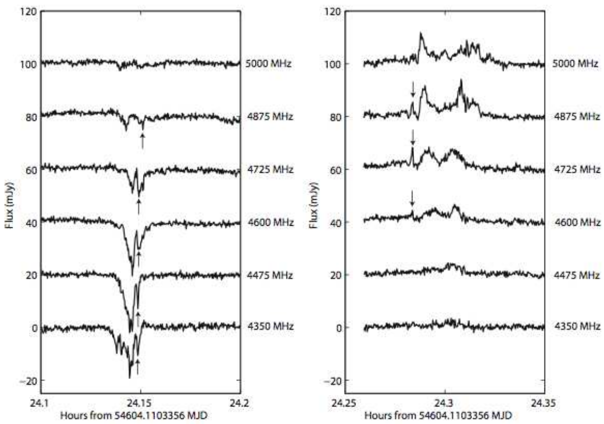

Figure 2: A left circularly polarized pulse with flux exceeding 20 mJy and a right circularly polarized pulse exceeding 15 mJy detected on 18 May 2008 with the Arecibo telescope. The presence of a structure with duration ~ 5 s and bandwidth < 375 MHz(arrows) can be used to place a lower limit on the brightness temperature of the emission of 10^{15} K.The temporal broadening from lower to higher frequencies and double peaked structure of the pulses may prove to be characteristic to the pulsed emission from ultracool dwarfs.

Acknowledgments

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