Proceedings of 12th Cambridge Workshop on Cool Stars, Stellar Systems, & The Sun, 2003 University of Colorado.

A Generalised 3-dimensional Model of Gyrosynchrotron Emission from Magnetic Structures on Active Stars

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Abstract. We present a computational model of gyrosynchrotron radio emission from generalised field structures in active stellar coronae. Any 3-dimensional field topology can be modelled but we have applied it to a generalised magnetic loop structure. The investigation has focussed on the effects of viewing angle, loop geometry, electron density and magnetic field strength on the radio brightness distribution and radio emission spectrum. Our results show that, not only is the observed radio flux critically dependent on viewing angle, in a non-intuitive manner, but that viewing angle also effects the overall spectral distribution. These results have important consequences for the interpretation of radio light-curves and radio spectra from active stars.

1. Introduction

RS CVn and Algol binaries are amongst the strongest stellar radio emitters. The emission is formed by mildly relativistic electrons moving along the magnetic field lines of the active components. For both types of binary, radio observations have revealed that the emission regions are extremely large, sometimes as large as the entire binary system. For both types of binary, radio emission is frequently observed along the centroid axis of the two components (Lestrade 1996; Gunn et al. 1997; Trigilio, Leto & Umana 1998; Gunn et al. 1999)

Much of the evidence for preferred emission sites in active binaries comes from radio light curves. In order to fully investigate the origin of this phenomenon, a better understanding of the factors that determine the form of the radio light curves in these systems is required. These factors are (a) the geometry of the system and observer, (b) the geometry of the emitting field structure and (c) the intrinsic directivity of the radio emission. (a) is easy to model given the orbital parameters and be can be modelled as a generalised magnetic loop or dipolar field topology. However, (c) requires a fully consistent gyrosynchrotron emission model.

In a previous paper we described results of a study of directivity in radio emission from active binaries (Brady & Gunn 2001). Here we present some preliminary results from an extension of this study into three dimensions. We discuss the gyrosynchrotron model and its application to a 3-dimensional magnetic loop model and present results for the effect of viewing angle on radio spectrum and radio light curve.

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2. The Model

In a stellar corona it can be assumed that radio waves propagate as they would in a fully ionised and collisionless medium where thermal motions are neglected. All motions are assumed to be induced by the electromagnetic wave which is then represented by two elliptically polarised modes. Using standard gyrosynchrotron expressions our model calculates emission and absorption coefficients, and hence the source function, throughout a grid of field strength and electron density. The intensity is calculated for a viewing plane outside the parameter space and mapped for any given viewing angle. A similar 2-dimensional model was presented by Klein & Trottet (1984).

A generalised magnetic loop structure in 3-dimensional space has been used in this investigation. A description of this standard is given by Brady & Gunn (2001); in summary the model consists of a homogeneous loop structure with a field strength of 3G, an electron density of 2.43×10^6 cm^{-3} and a power law energy spectrum of index 3. The loop is represented by a collection of dipole field lines containing a plasma in hydrostatic equilibrium with injected energetic electrons. The loop is divided into a number of elements in three dimensions, each of which are assumed to be a homogeneous source of emission. Using the gyrosynchrotron model an investigation has been made of the effects of viewing angle, loop geometry, electron density and magnetic field strength on the radio brightness distribution and the observed radio spectrum. Figure 1 shows some examples of the model results.

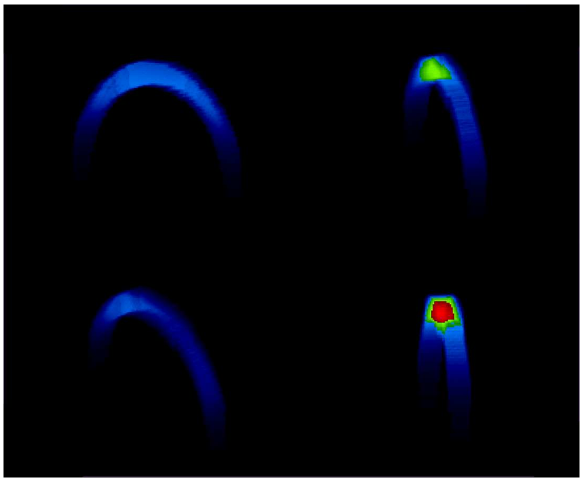

Figure 1. The modelled gyrosynchrotron emission from a standard model loop as a flux brightness distribution. The emission varies substantially with viewing angle and has an integrated maximum at 35°longitude, 10°latitude (top left). The bottom right panel shows the loop at position 80°longitude, 10°latitude where the flux is highly concentrated in the loop apex although the integrated flux is less than at top left. The other panels show the loop at intermediate positions.

3. Lightcurves

The observer's viewing angle with respect to a surface magnetic loop is crucial to the measured radio flux and brightness distribution. As an example of this we have considered the radio light curve formed by a single standard loop located at various latitudes as it rotates from limb to limb of the stellar surface. Figure 1 shows our results for this analysis.

For a loop at 0°latitude the peak total flux occurs when the loop is approximately 10°from the stellar limb toward the observer. In this case zero flux occurs when the loop's central axis is pointing toward the observer (longitude 90°). For loops at higher latitudes the peak emission occurs at smaller and smaller angles with the observer. A minimum, but non-zero flux then occurs offset from the loops central axis. These results are for a loop which has no surface longitudinal component (i.e. the footpoints are at the same longitude on the stellar surface). Further periodic variations occur when the loop is given a longitudinal component. These interesting features are due to the complex interaction between the gyrosynchrotron emission cones from different parts of the magnetic loop and the interplay between emission/absorption processes with the observer's viewing angle.

These results have shown that, if the radio emission from an active star is dominated by a single, large loop structure, the resulting radio light curve is extremely variable and is critically dependent on the observer's viewing angle.

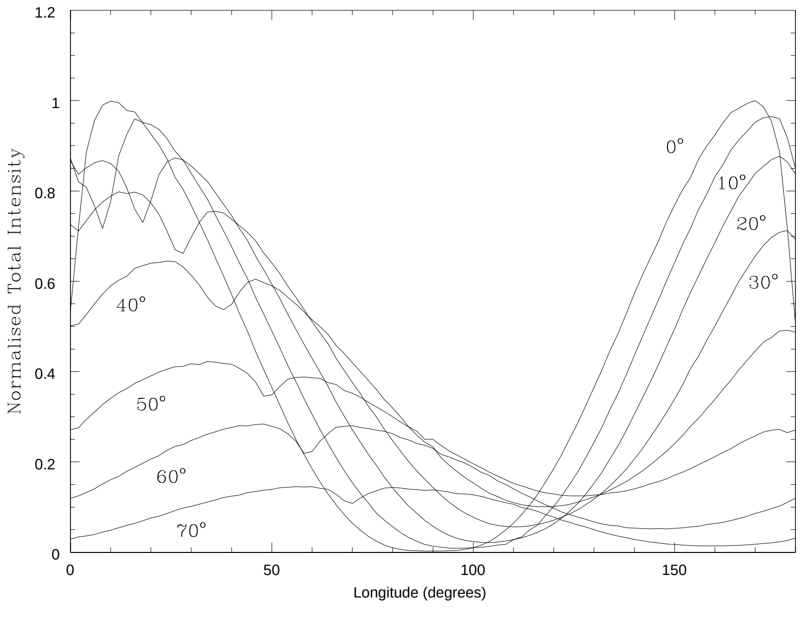

Figure 2. Variation of the total integrated flux (normalised) from the standard loop model with longitude (limb to limb) for various values of the loop latitude from 0°to 80°.

4. Spectra

Our models have also shown that the viewing angle of the observer with respect to the standard loop also effects the total integrated observed radio spectrum. These changes in the observed spectra are also due to the changing orientation of the complex set of gyrosynchrotron emission cones within the loop. Our process involves a summation of the gyrosynchrotron emission spectra from each individual element of the loop model. This forms the total observed radio spectrum for an individual loop geometry and viewing angle.

Some of these results are depicted in Figure 2 which shows the radio spectra of loops placed on the stellar limb but at various latitudes from 0°to 80°. As shown, the highest level of radio emission occurs between 0°and 20°latitude. The peak in the radio spectrum first increases from 0°towards the latitude of the greatest integrated flux, then decreases once again towards even higher latitudes. There is also great variation in the flux levels for a model loop at different latitudes at a given observing frequency. In this example, the total flux varies by an order of magnitude between latitudes of about 10°and 80°. The results show that even moderate changes in viewing angle can produce a shift in the peak emission frequency of up to 1GHz. Note that the commonest observing frequency for active stars in the radio is 5GHz.

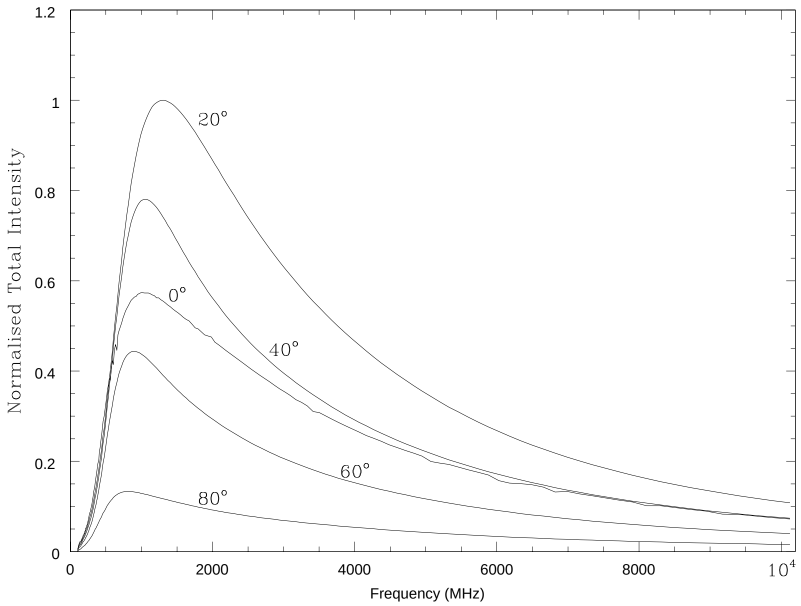

Figure 3. The total integrated radio spectrum from a standard loop located on the stellar limb for loop latitudes from 0°to 80°. Note that the common observing frequency for radio observations of active stars is 5000MHz.

5. Conclusions

This model has been significantly expanded from that presented by Brady & Gunn (2001). It has become clear through this study that directivity is a major consideration in the discussion of radio light curves, particularly where such emission may be dominated by a single magnetic loop in the stellar corona. We have shown that the emission from such a loop is dependent on viewing angle in a non-intuitive and complex manner. Furthermore, the observed radio spectrum is heavily dependent on viewing angle also. This has important consequences for the interpretation of radio light-curves and radio spectra from active stars.

Acknowledgments. PAB acknowledges support through PPARC Phd Grant PPA/S/S/1997/02580.

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