Flaring Stars and the Long Wavelength Array

Rachel Osten[1,2]

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1. Introduction

Coherent emission appears to be a common phenomenon on radio-active late-type stars. Solar radio flare emissions below 3 GHz are rich and varied, arising from coherent processes in the upper solar atmosphere (Dulk 1985; Isliker & Benz 1994). Studies of decimetric radio emission from M dwarf flare stars have led to discovery of high brightness temperature, highly circularly polarized bursts (Bastian et al. 1990) generally attributed to plasma radiation or emission from an electron-cyclotron maser. Observations, mainly at L-band, have revealed that highly circular polarized emission from active binary system (RS CVn and BY Dra binaries) coronae is fairly common, probably also produced by a coherent mechanism (White & Franciosini 1995). Even more recently, some very low mass stars and brown dwarfs have been observed to undergo highly circularly polarized bursts, generally at higher frequencies (5–8 GHz; Burgasser & Putman 2005). All three of these classes of stars can be considered as potential Long Wavelength Array (LWA) sources. As discussed below, there are more than a thousand potential LWA stellar sources of these three classes, and we expect a large number of detections from these (as well as detections from more distant objects).

2. Flare Stars

Radio bursts on nearby flare stars have been observed for many years, beginning with Spangler et al. (1974). L-band radio bursts are characterized by large flux density enhancements – as large as ≈ 500 times the quiescent flux density level of typically a few mJy – that can occur on very short time scales (< 0.02 seconds). The degree of circular polarization of the radio bursts is typically very high, often reaching 100% (Lang et al. 1983, Güdel et al. 1989, Bastian et al. 1990, Abada-Simon et al. 1997). Spectroscopic investigations of the radio bursts are necessary to determine both the intrinsic bandwidth and timescales of the phenomena, key measurements which will help constrain emission mechanisms.

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[1] Hubble Fellow

[2] University of Maryland

Osten & Bastian (2006) used observations to determine the characteristics of small time-scale radio bursts from the nearby flare star AD Leo. Light travel time arguments imply source regions less than a percent of the stellar radius. The mean duration for each sub-burst was 0.03 s. Plasma radiation is favored over electron-cyclotron maser emission due to the hot, dense coronal environment found in AD Leo and flare stars. In comparison to the solar corona, in which the bulk of X-ray emitting thermal plasma lies at 1–2 MK, flare star coronae have temperatures of 6–20 MK. Electron-cyclotron maser radiation at the first or second harmonic can be readily gyroresonantly absorbed at the second or third harmonic layers, respectively. In contrast, plasma radiation will be most affected by free-free absorption, which decreases with increasing temperature, hence favoring the escape of radiation from a hot plasma.

At the other extreme, periods of enhanced circularly polarized emission can last for hours, even days (Slee et al. 2003). Whether this results from the same intrinsic phenomena producing the isolated bursts is presently unknown.

The occurrence rate for radio bursts can be estimated by using the statistics discussed by Abada-Simon & Aubier (1997), who compute the probability to observe n bursts as $P(n) = a^n \exp -a/n!$, where $a = 11N/38.3$ uses the L-band burst rate they observed from AD Leo (for bursts with peak flux densities $\sim$ 8mJy or higher, durations 6 s or longer), and assuming all flare stars have the same intrinsic radio burst properties. For N of 2 hours or higher, the probability of observing one or more burst is $> 30\%$. Bursts appear to have significant clumping in time, however, necessitating longer observing times to increase the probability of a definite detection. In two past observing sessions at Arecibo, Osten & Bastian have observed for 16 hours each session and obtained detections over 100 mJy spanning a few minutes.

Flare stars are classified primarily on the basis of their behavior at optical wavelengths, but radio emission appears to be a common characteristic as well. White et al. (1989) detected 40% of surveyed flare stars with the VLA at 20 and 6 cm. A larger fraction of nearby flare stars is presumed to be radio-active, taking into consideration variability. A new catalogue of solar vicinity flare stars by Gershberg et al. (1999) includes 463 objects out to a maximum distance of $\approx$ 50 pc.

3. Active Binaries (RS CVn, BY Dra Binaries)

Active binary systems share many characteristics with M dwarf flare stars, despite the disparity in physical characteristics. Evidence for starspots, intense and variable chromospheres and coronae, X-ray and radio flares with similar characteristics deduced on single active stars and active binaries suggests a common origin. Active binary systems can be broken up into two broader groups: RS CVn systems, composed of an evolved G–K type primary, and BY Dra systems, composed of late K/early M dwarf primary, and cooler secondary. Polarized bursts from active binary systems have been noted for over two decades (Mutel & Weisberg 1978, Fix et al. 1980). Low frequency observations are well-matched to the range of values of the electron gyrofrequency and plasma frequency inferred in the coronae of active stars; radiation at the fundamental or second harmonic of these frequencies is expected if plasma radiation (ν_p) or cyclotron maser emission (ν_B) is present. van den Oord & de Bruyn 1994 detected intense polarized radiation from another active binary system, II Peg, at 360 MHz. Osten et al. (2004) found numerous examples of L-band bursts, some lasting minutes while most persisted for hours. Such activity appears to be common: out of the cumulative 10.8 days of L-band data, $\approx 33\%$ of the time moderately or highly left circularly polarized emission was observed. The Catalog of Chromospherically Active Binary Systems (Strassmeier et al. 1993; CCABS) lists 206 active binaries within ~ 200 pc — at the largest distances, the catalog is limited by completeness issues. Drake et al. (1989) detected 66 out of 122 surveyed RS CVn and related binary systems at a frequency of 5 GHz. Again, we consider the number of such systems capable of producing radio flares to be higher, based on variability considerations.

4. Very Low Mass Stars & Brown Dwarfs

Much less is known about the nature of coherent radio emission from very low mass stars and brown dwarfs. The first discovery of gyrosynchrotron emission and flare from an M9 dwarf was made by Berger et al. (2001). Since that time, a handful of flares have been detected from these objects, which have a high degree of circular polarization, akin to what is seen in M dwarf flare stars. The large flux densities and circular polarization levels argue for a coherent mechanism. Indeed, recent papers have discovered periodic rotational modulations of a few ultracool dwarfs (Hallinan et al. 2006, 2007) which show significant amounts of circular polarization at cm wavelengths. However, the ultracool nature of these very low mass stars makes it difficult to extrapolate the same mechanism, as the magnetic activity signatures commonly seen in flare stars (Hα emission, X-ray emission, radio emission) are only sporadically detected. At present, roughly 648 known L & T dwarfs are known (http://spider.ipac.caltech.edu/staff/davy/ARCHIVE/) at maximum distances of ~ 80 pc. The 2MASS, DENIS, and SDSS surveys have also identified roughly 180 ultracool M dwarfs (M7V–M9V) within ~ 35 pc (Cruz et al. 2003). At present, radio emission has been detected in objects as cool as L5 (Berger 2002), with an overall detection rate of $< 10\%$.

5. LWA Specifications and Sensitivities

The accompanying figures show the range of LWA applicability for flare stars (**Figure 1**) and active binary systems (**Figure 2**), assuming brightness temperatures for coherent radiation of 10^{14} and 10^{16} K, respectively, and source sizes comparable to the stellar disk; 0.3 $R_\odot$ in the case of flare stars, and $2R_\odot$ for the active binary case. The sensitivity of the LWA in 1 hour at 20 MHz is given as a dotted line.

The most important parameters for LWA specifications as regards the ability to detect emission from flare stars is spatial resolution, to unambiguously identify the source of transient emission (current specifications of 8 and 2 arcseconds at 20 and 80 MHz, respectively, are sufficient for this); time resolution to search for substructure in the bursts (at L band current limits are several ms but we expect that the timescales increase with decreasing frequency; temporal resolution of 1 ms should suffice); frequency coverage to track the behavior of bursts in the time-frequency domain (the widest possible coverage is desireable here, a total bandwidth of 8 MHz or more should suffice); and circular polarization. Particularly for nearby objects with known (and small) dispersion measure, the trend of bursts in frequency and time is necessary to examine substructure as well as constrain intrinsic frequency drift of bursts. Finally, circular polarization measurements are needed to determine if the burst emission is intrinsically circularly polarized; bursting behavior at higher frequencies indicates large amounts of circular polarization.

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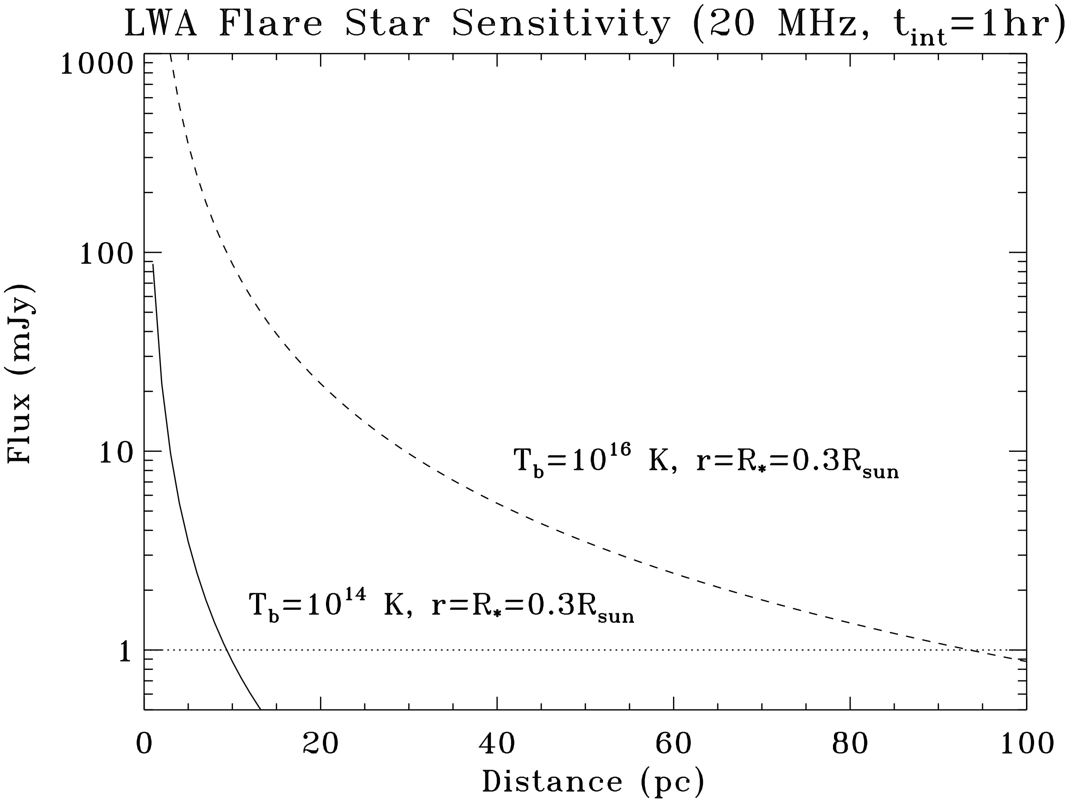

Fig. 1: Plot shows the anticipated flux from flare stars as a function of distance to the star. The solid line assumes a brightness temperature for coherent radiation of 10^{14} K while the dashed line represents 10^{16} K. The source sizes were assumed to be comparable to the stellar disk which is 0.3 $R_\odot$ for flare stars. The dotted line shows the full LWA sensitivity at 20 MHz in 1 hour of integration.

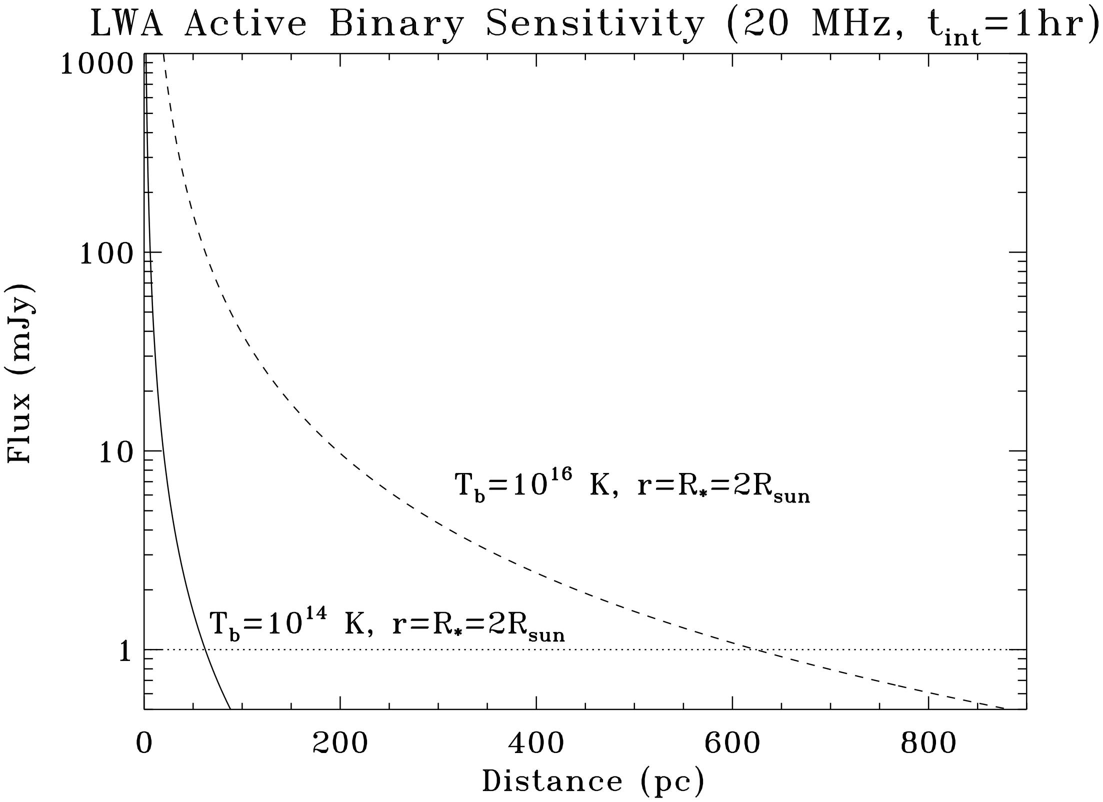

Fig. 2: Plot shows the anticipated flux from active binary systems as a function of distance to the star. The solid line assumes a brightness temperature for coherent radiation of 10^{14} K while the dashed line represents 10^{16} K. The source sizes were assumed to be comparable to the stellar disk which is 2 $R_\odot$ for active binaries. The dotted line shows the full LWA sensitivity at 20 MHz in 1 hour of integration.