High-Resolution Dynamic Spectrum of a Spectacular Radio Burst from AD Leonis

Meil Abada-Simon[1,2], *Alain Lecacheux*[2], *Monique Aubier*[2,3], *Jay A. Bookbinder*[4]

[1] Sterrekundig Instituut, 3508 TA Utrecht, The Netherlands
[2] ARPEGES - URA CNRS 1757, Observatoire de Paris, 92190 Meudon, France
[3] Université Paris 6, France
[4] Smithsonian Astrophysical Observatory, Cambridge, MA 02138, USA

1 Introduction

AD Leonis is a very active, single dMe flare star. The similarities between this type of star and the Sun has led to study their radio radiation, which originates from their corona. The high brightness temperatures and other characteristics of most dMe radio bursts can be attributed to a non-thermal, coherent mechanism: plasma radiation or a cyclotron maser instability (CMI) are both plausible explanations. Even for the strongest burst of AD Leo which reached 940 mJy at 21 cm, it was not possible to discriminate between these two mechanisms (Bastian et al. 1990).

Here we present an intense burst from AD Leo, exhibiting strong spikes for which the CMI seems to be the only reasonable explanation. In Sect. 2 we describe the observations, and in Sect. 3 we give an interpretation for this event.

2 Observations

We used the 305 m diameter Arecibo radio telescope to observe simultaneously the star ("ON") and another direction in the sky ("OFF") at 1.4 GHz, in both senses of circular polarization, to discriminate between flares of stellar origin and artificial radiofrequency interference. An acousto-optical spectrograph (AOS) recorded every 20 ms four spectra of 50 MHz bandwidth, and the frequency resolution was ~1 MHz. The observational technique used during that campaign is described in detail in Abada-Simon et al. (1994).

The event, starting at 4:12:55 UT on 13 February 1993, is the most interesting of the dozen bursts detected from AD Leo during the campaign mentioned above. This event is 100% right circularly polarized (RCP), and exhibits a variety of characteristics in frequency and time.

Fig. 1 shows the dynamic spectrum (1 s integration time) of the burst's most interesting part, but the total duration of the event is $\sim$ 7 min. The emission frequency increases and decreases with time at several instants; these positive and negative drifts give: $|df/dt| \simeq 1 - 5$ MHz.s^{-1}; they form "arches" which

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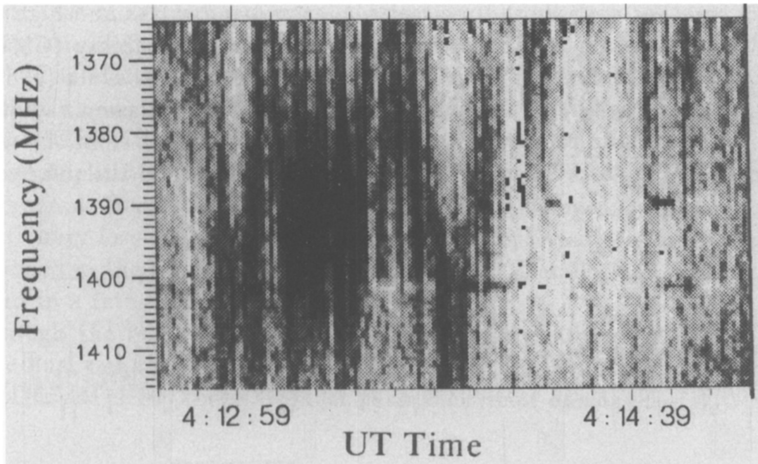

Fig. 1. RCP dynamic spectrum of 2.5 min observation of AD Leo on 13 February 1993. Each pixel represents 1 s of time and one channel of 0.5 MHz bandwidth. The frequency ranges from 1365 MHz to 1415 MHz. Time is in UT. Intensity is represented in grey levels. White-to-black represents an increase of $\sim$ 70 mJy.

spread over $\sim$ 10-20 s. Unfortunately, because of the limited observing bandwidth (50 MHz), one cannot see to which frequencies the emission actually extends. In addition, its instantaneous bandwidth varies with time from $\sim$ a few MHz to 50 MHz or more. Oscillations on a quasi-period of $\sim 5 - 10$ s are also present, which are more obvious at frequencies $\leq$ 1400 MHz.

Fig. 2a shows the time variations of four 10 MHz integrated bands over 5 s taken out of the burst's most intense parts, and plotted with 20 ms time resolution: one can clearly see the numerous spikes present in the burst, their flux density reaches up to 350 mJy from a quasi-zero level in 20 ms, which suggests that, maybe, a higher flux density could have been measured with a shorter time resolution. Fig. 2b shows a full resolution dynamic spectrum of four seconds taken out of the burst of AD Leo: the black vertical rectangles surrounded by two white ones show again that a high flux density is reached in no more than 20 ms from a zero level (in white). Fig. 2b also shows that the instantaneous bandwidth of each spike is Δf $\simeq$ 10-20 MHz, which corresponds to a relative bandwidth of $\Delta f/f \approx$ 1%. Finally, some of the spikes exhibit a frequency drift: $df/dt \simeq 400$ MHz s^{-1}.

3 Interpretation

The shortest time variations ($\Delta t = 20$ ms) infer a source size $\leq$ 6000 km. With flux densities reaching up to $\sim$ 350 mJy, we deduce a brightness temperature $T_b \geq 10^{15}$ K. A plausible mechanism explaining such a high brightness tem-

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perature, together with short time scales, narrow bandwidths and high degrees of circular polarization is the electron–cyclotron maser instability (CMI). This process has been reviewed by Wu & Lee (1979), Melrose & Dulk (1982), and recently favored (again) by Melrose (1994), rather than plasma radiation, to explain the flare star radio bursts. Similar spikes to those from AD Leo are observed from the auroral regions of magnetized planets and the solar corona.

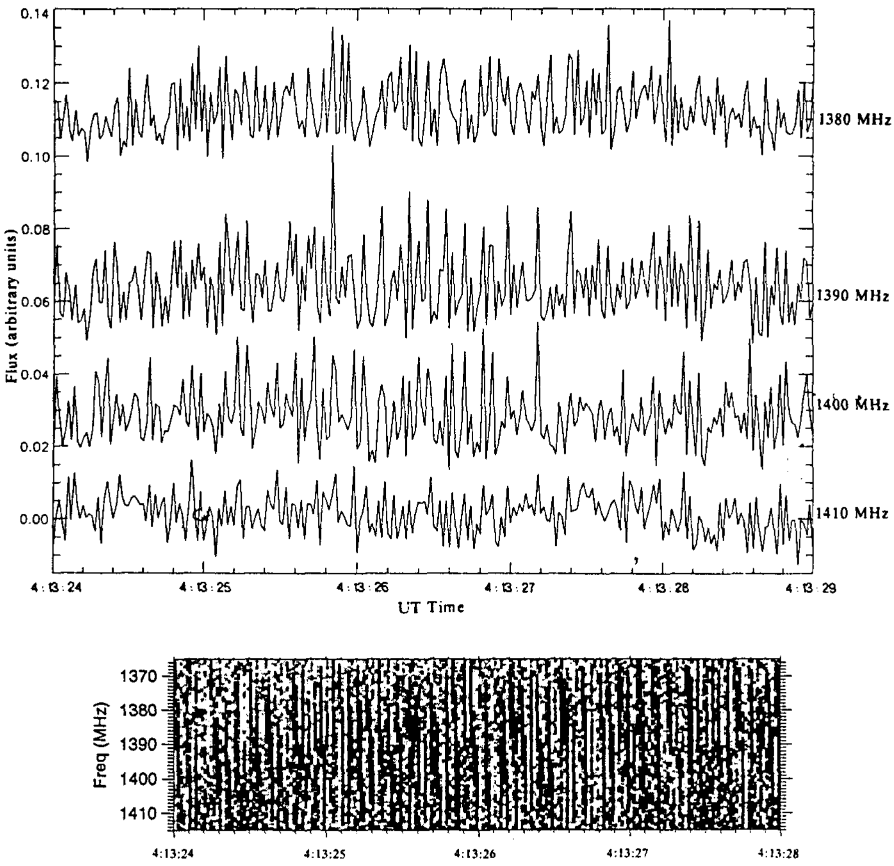

Fig. 2. *Top:* Ttime variations in RCP in AD Leo over 5 s for four 10 MHz integrated bands centered at 1380, 1390, 1400 and 1410 MHz, respectively, from top to bottom. The time resolution is 20 ms. The vertical axis is in arbitrary units, but the flux density is indicated by the r.m.s error bar: 1 $\sigma \simeq$ 39 mJy, which corresponds to 0.005 in arbitrary units. The most intense spike, which is best visible in the band centered at $\sim$ 1390 MHz, occurred at 4:13:25.84 UT and reached $\sim$ 350 mJy. *Bottom:* RCP dynamic spectrum of AD Leo on 13 February 1993 over 4 s. Each pixel represents 20 ms of time and one channel of 0.5 MHz bandwidth. White to black represents an increase of $\sim$ 400 mJy.

In the case of cyclotron maser emission, our observations at 1400 MHz lead to a magnetic field B $\simeq$ 500 G for an emission at the fundamental frequency ($s = 1$). The electron number density in the source is not known. Thus, an emission on the X-mode or on the O-mode, at $s = 1$, is possible, depending on the value of the ratio $\frac{\omega_p}{\Omega_e}$ (see Benz 1993).

In our application of this mechanism we will use the theory developed by Aschwanden & Benz (1988a,b): an electron-cyclotron masing source operating in a stationary loss-cone can explain the spiky intense radio emission, as one of us developed in the solar case (Barrow et al. 1994). Detailed calculations will be presented in a future paper.

Although the burst in AD Leo presents similar features to those observed from the Sun, one should keep in mind one of the most striking differences: AD Leo's spikes are $\sim 10^4$ times stronger than their solar analogues.

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L. Pustil'nik: You only use the Melrose model on the cyclotron maser emission. Another process with polarized burst generation by plasma waves on hybrid-frequency generation (Stepanov and Zaitsev models) is possible, and gives the same result for burst emission. Why did you not analyse these possibilities? Do you have any observational reasons for this?

M. Abada-Simon: It is the spikes that I attribute to electron-cyclotron maser emission, using not only Melrose's recent publication in favour of this mechanism, but also by analogy with spikes having similar characteristics to those observed from the magnetized planets and the sun. A solar burst similar to that observed in AD Leo was studied by Aschwanden & Benz (1988): they also explain several of the observed features in the frame of the cyclotron maser occuring in certain conditions.

I am not aware of another mechanism which produces very intense spikes with strong circular polarization and narrow bandwidth in the same context (same frequency, etc.). However, I shall consider your suggestion.

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