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Four Stokes Parameter Radio Frequency Polarimetry of a Flare From AD Leonis

by

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ABSTRACT

Observations of the four Stokes parameters of a 430 MHz flare from the UV Ceti-type star AD Leonis are presented. The maximum amplitude of the event was 0.52 flux units and the durations at one-half and one-tenth maximum were 12 and 40 seconds, respectively. The degree of circular polarization at maximum intensity was approximately 56 percent and was later observed to be as high as 92 percent. Linear polarization was also observed at a level of about 21 percent at flare maximum which allowed an upper limit of 440 radians - m^2 to be placed on the rotation measure.

I. INTRODUCTION

While observations of radio frequency flares from UV Ceti-type stars by several groups of investigators including ourselves (Lovell 1971, 1974; Higgins, Solomon, and Bateson 1968; and Spangler, Shawhan, and Rankin 1974, hereafter referred to as Paper I) have appeared in the literature, no one to our knowledge has yet reported polarimetric studies of these events. In view of the considerable interest inherent in such a series of measurements, a radio flare star polarimetry program was undertaken at Arecibo Observatory during the first quarter of 1974. Although radio frequency flares from the UV Ceti-type star AD Leonis were reported for the first time in Paper I, this star exhibits great activity in both the radio and optical regimes, and thus was monitored extensively throughout the course of the program. On 1 April 1974 the largest flare as yet observed at 430 MHz occurred on AD Leo[+] with an amplitude at maximum intensity of 0.52 flux units (1 f.u. = $10^{-26} Wm^{-2} Hz^{-1}$). The most notable aspect of the flare was its strong right-hand circular polarization (56 percent at maximum intensity and more than 90 percent toward the end of the outburst); linear polarization was also observed but to a somewhat **lesser extent**

[+]1974 March 31 Atlantic Standard Time; the unfortunate date of occurrence should not be considered among the sources of experimental error.

(21 percent at maximum intensity). The discussion of the AD Leo flare in the present letter constitutes a preliminary report on the program of polarimetric flare star observations; a more detailed discussion of the remainder of the events will appear in a subsequent publication.

II. INSTRUMENTATION

The polarimeter system used in the observations was a modification of that used for pulsar measurements by Rankin, Campbell, and Backer (1974). Briefly, the system consists of a dual-circularly-polarized, 430-MHz line feed, two identical parametric receivers with Gaussian-shaped passbands of 2-MHz equivalent width, and an adding polarimeter at the 30-MHz intermediate frequency. The receivers were stabilized and calibrated via alternating pulsed noise sources. The four detected outputs from the polarimeter together with that of the off-star interference monitor (see Paper I) were interfaced to an on-line CDC 3300 computer. Data channels incorporating an integration time constant of 100 msec were recorded in order to avoid possible interference contamination, but were later smoothed to one second for analysis and display. Prior to observation of AD Leonis, the flux-density scale of the system was calibrated relative to that of Kellermann, Pauliny-Toth, and Williams (1969) by a drift scan on 3C234. The origin of the polarization position angle was not determined, so only changes in this quantity could be measured. Errors in the determination of the Stokes parameters Q, U, and V due to instrumental causes were estimated from radar astronomical measurements of the ellipticity of the circularly polarized ports of the line feed (Campbell 1974).

The small departure from pure circularity resulted in a mutual "contamination" of the circular and linear Stokes parameters (Campbell, Rankin, and Spangler 1974). In all cases the definition of polarization parameters follows the convention of Kraus (1966).

III. EXPERIMENTAL RESULTS

Figure 1 gives the behavior of the four Stokes parameters and the off-star interference monitor at the time of the flare. The stellar origin of the event is demonstrated by the absence of significant activity in the off-star channel. Errors of a statistical nature are indicated by the error bars, which were calculated from the pre-flare baseline for each of the Stokes parameters. Errors due to instrumental polarization were estimated to be smaller than the statistical errors in the case of V, and one to three times larger than the statistical errors in the case of Q and U. The observed linear polarization is thus significantly larger than any possible instrumentally induced effect. Moreover, the fact that Q and U are not morphologically identical to V (which would be the case if they were simply the manifestation of a substantial instrumental defect) provides further support for the reality of the observed linear polarization.

Inspecting Figure 1 in detail we note that I, V, and U show a strong maximum at about $2^h\ 57^m\ 13^s$ U.T. which takes about six seconds to decay. Both I and V then decrease to a plateau where they remain for approximately 20 seconds at about half maximum intensity. Two impulsive components of roughly one second duration are seen in the I and V channels at $57^m\ 25^s$ and $57^m\ 35^s$. The first of these spikes is not observed in the linear channels, although the second one clearly occurs in Q. In addition, fluctuations of approximately 0.05 flux units are seen in V between $57^m\ 20^s$ and $57^m\ 40^s$. The amplitudes of these variations are much larger than the statistical fluctuations; these features may then have originated in the source region or may be the result of scintillation. Comparison of the pre-flare and post-flare baselines shows evidence for low level flare activity persisting up to a minute after the end of the most intense phase of the event. The two second data gap between $57^m\ 14^s$ and $57^m\ 16^s$ represents data lost due to a post-detection receiver adjustment during the flare.

Figure 2 shows the variation during the flare of the degree of circular polarization (V/I), the degree of linear polarization, $[(Q^2 + U^2)^{\frac{1}{2}}/I]$, and the polarization orientation angle $[1/2 \tan^{-1} (U/Q)]$. Errors were calculated for each point, and the linear polarization was corrected for "statistical polarization" resulting from the fact that the total linear polarization $[(Q^2 + U^2)^{\frac{1}{2}})]$ is Rician rather than Gaussian distributed (Whalen 1971). This statistical contribution to the fractional linear polarization was typically one or two percent except at the beginning and end of the flare where it was somewhat larger. The uncertainty in the degree of linear polarization due to instrumental defects was less than about 20 percent of the observed value until $57^m\ 20^s$ and less than about 30 percent thereafter.

Table 1 summarizes the main characteristics of the flare. The maximum amplitude was 0.52 flux units and the durations at one-half and one-tenth manimum were 12 and 40 seconds, respectively. The degree of circular polarization at maximum amplitude was approximately 56 percent and was later observed to be as high as 92 percent. The fractional linear polarization was about 21 percent at flare maximum, which was not significantly different than the maximum value of 23 percent.

IV. DISCUSSION

The most notable aspect of the AD Leonis flare was its strong circular polarization. The degree of circular polarization was comparable to that observed in solar decimetric continuum bursts (Kundu 1965) which invites the speculation that the respective emission mechanisms are similar (i.e., gyrosychrontron radiation of intermediate energy electrons in a magnetoactive plasma). In the solar case, propagation effects in the source region play a significant role, and observed variations in the sense and degree of circular polarization as a function of frequency yield appreciable information on conditions in the flare region (Zheleznyakov 1970). Although the present single-frequency measurements admit only speculation in this regard, it may well be that the high degree of circular polarization indicates that 430 MHz is far from plasma resonance frequencies where propagation effects are most evident. Caution must be exercised, however, in applying solar flare models to these events as Shlysh (1965) has pointed out that a coherent radiation mechanism may be involved.

The observed linear polarization, on the other hand, does allow some constraints to be placed on conditions in the region through which the flare radiation propagates; the maximum amount of Faraday depolarization consistent with the observed linear polarization yields an upper limit to the Faraday rotation in the atmosphere of AD Leonis. Integration of the linear Stokes parameters over the Gaussian-shaped passband yields the following relationship between the observed degree of linear polarization and that at the source (or that which would be observed with an arbitrarily narrow passband)

$$\frac{m_o}{m_s} = \exp\left[-\frac{4}{\pi}\left(\frac{c^2\ RM\ \Delta\nu}{\nu_o^3}\right)^2\right] \qquad (1)$$

where m_o is the observed fractional linear polarization, m_s the fractional linear polarization at the source, c the speed of light, RM the rotation measure, $\Delta\nu$ the equivalent width of the passband, and ν_o the radio frequency. At maximum flare amplitude the circular and linear polarizations were 56 and 21 percent, respectively, resulting in a maximum possible fractional linear polarization at the source (m_s) of 83 percent. Equation (1) then yields a maximum rotation measure of about 440 radians-m^2 or a total Faraday rotation at 430 MHz of less than $\sim$ 215 radians. While the measured upper limit includes contributions from the intervening medium, they are thought to be small compared to the above value. [The ionospheric Faraday rotation was determined to be $\sim$ 0.15 radians at 430 MHz, while a limit on the rotation in the interplanetary and interstellar medium of $\leqslant$ 2 radians (at 430 MHz) can be obtained from the rotation measures of pulsars at roughly the same galactic latitude as AD Leonis (Manchester, 1974).] The upper limit of 440 radians $-m^2$ represents a total path integral of $\leqslant 1.7(10)^{15}$ Gauss-cm^2 which is apparently somewhat smaller than values typically encountered in solar decimetric continuum bursts.

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TABLE 1

FLARE CHARACTERISTICS

Maximum amplitude	0.52 flux units
Duration (half maximum)	12 seconds
Duration (one-tenth maximum)	40 seconds
Degree of circular polarization at flare maximum	56 percent
Maximum value of degree of circular polarization	92 percent
Degree of linear polarization at flare maximum	21 percent
Maximum value of degree of linear polarization	23 percent

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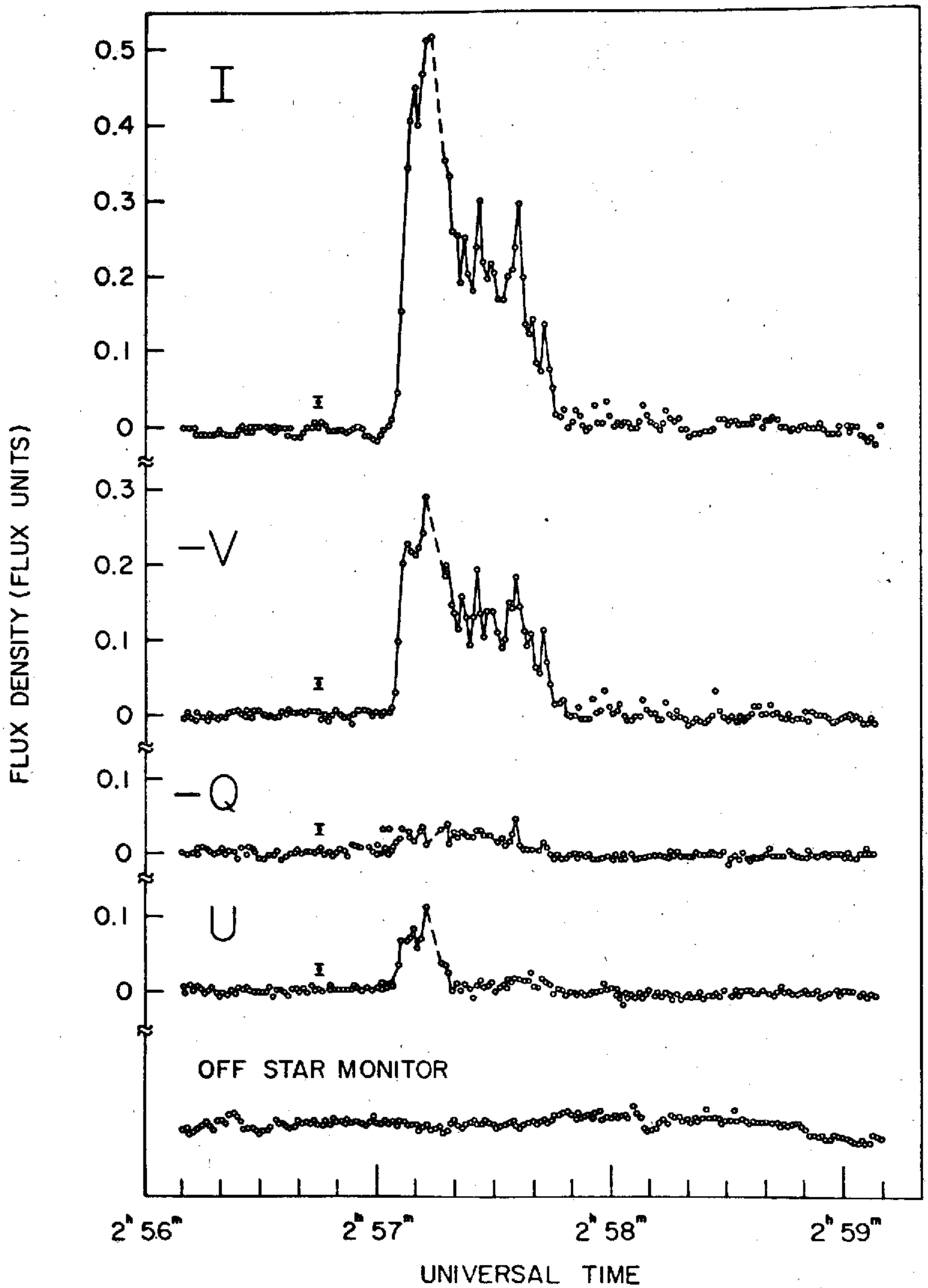
FIGURE CAPTIONS

Figure 1 Stokes parameters I, Q, U, and V and the off-star interference monitor during the flare from AD Leonis.

Figure 2 Variation during the flare of the (a) degree of circular polarization (V/I), (b) degree of linear polarization $[(Q^2 + U^2)^{\frac{1}{2}}/I]$, and (c) position angle $[1/2 \tan^{-1} (U/Q)]$.



FLUX DENSITY (FLUX UNITS)
0.5
0.4
0.3
0.2
0.1
0
I
0.3
0.2
0.1
0
−V
0.1
0
−Q
0.1
0
U
OFF STAR MONITOR
2h 56m
2h 57m
2h 58m
2h 59m
UNIVERSAL TIME

FIGURE 1

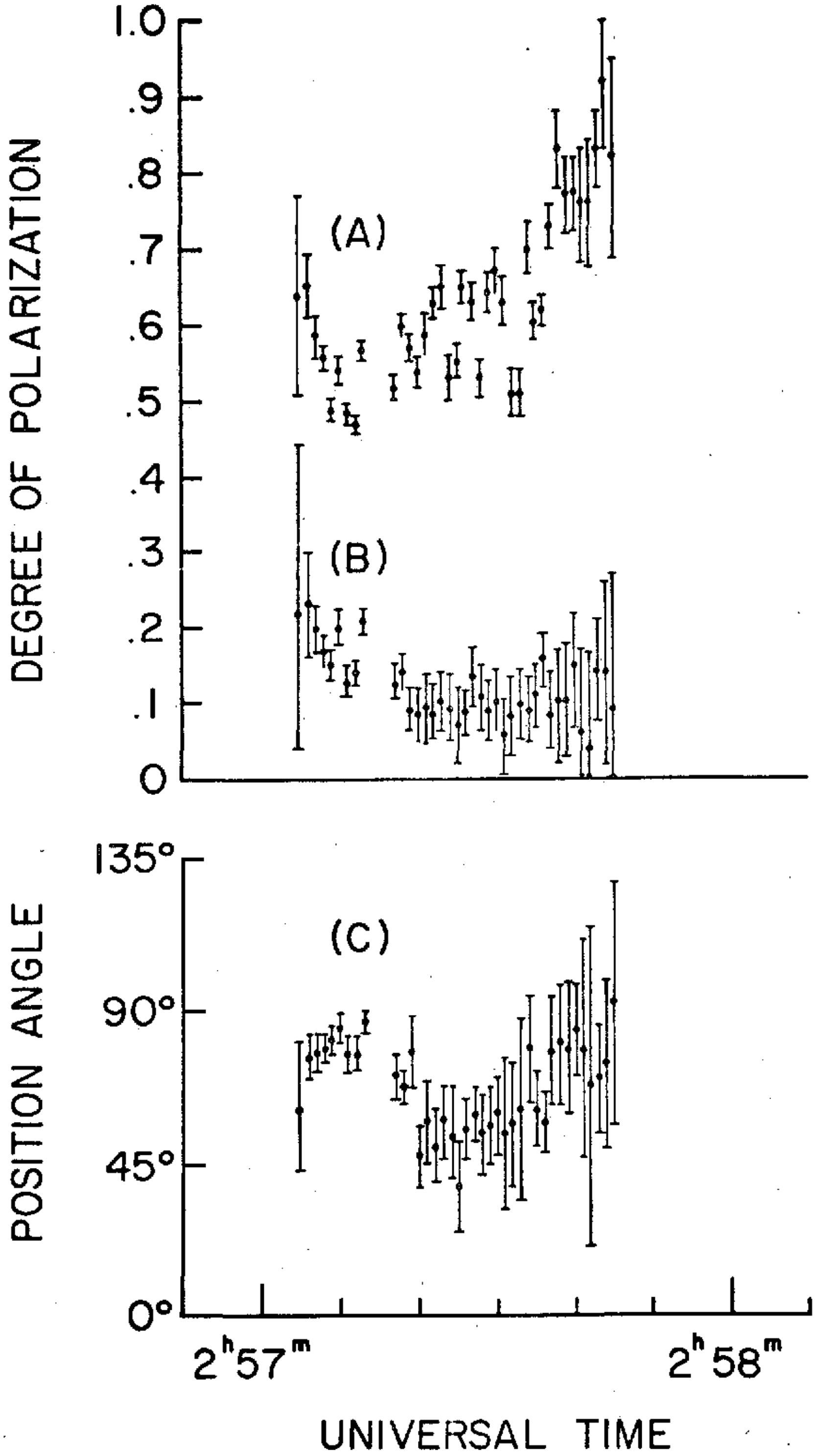

1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
DEGREE OF POLARIZATION
(A)
(B)
135°
90°
45°
0°
POSITION ANGLE
(C)
2h57m
2h58m
UNIVERSAL TIME

FIGURE 2