The Enigmatic F0V Star 47 Cas

M. Güdel
Paul Scherrer-Institut, CH-5232 Villigen PSI, Switzerland

A. O. Benz
Institut für Astronomie, ETH Zentrum, CH-8092 Zürich, Switzerland

E. F. Guinan
Villanova University, Villanova, PA 19085, USA

J. H. M. M. Schmitt
MPI für Extraterrestrische Physik, D-85740 Garching, Germany

Abstract. New microwave observations of the young, extremely active F0 V star 47 Cas are presented. A week-long flaring episode is interpreted in terms of a trap plus loss model.

1. Introduction

In the course of a VLA search for F type radio stars, we discovered a strong source at the position of the F0 V star 47 Cas. It coincides with a luminous X-ray source identified in the ROSAT X-ray All-Sky Survey. 47 Cas shares its space motion ([U,V,W] = [-7.9, -29.7, -8.0] km s\(^{-1}\)) with the Pleiades Moving Group, and may thus be a very young star near the Zero-Age Main Sequence. Quiescent luminosities are \(1.2 \times 10^{15}\) erg s\(^{-1}\)Hz\(^{-1}\) at 8.4 GHz and \(2.8 \times 10^{30}\) erg s\(^{-1}\) in the soft X-rays (distance = 38 pc), making this star one of the most luminous quiescent coronal sources on the main sequence.

2. New Observations and a Trap Model

We obtained a series of 21 short (\(\sim 40\) minutes) VLA 8.4 GHz (100 MHz bandwidth) observations spread over 9 days in September 1994. One 20-6-3.6 cm spectrum was also recorded. Apparently, 47 Cas was in a state of extensive flaring, with fluxes reaching 13 mJy and variability on timescales of tens of minutes to hours (see Güdel 1995). The weakly (\(\leq 15\%\)) polarized emission suggests gyrosynchrotron emission from trapped electrons. Several flare decays are nearly exponential.

We modeled the flare decays assuming a perfect magnetic trap in which episodically injected, accelerated relativistic electrons lose their energy by colli-
Figure 1. Contour plot illustrating $1/e$ decay times (in seconds) of a power-law distribution of nonthermal particles injected into a source homogeneous in $B$ and $n_e$. Loop stability requires solutions above the diagonal. The shaded areas indicate ranges appropriate for several flare portions (see Güdel 1995). The power-law exponent of the initial particle distribution is $\delta = 3$.

 emissions and synchrotron radiation in a magnetic field of strength $B$:

$$- \frac{d\gamma}{dt} \approx C + S\gamma^2$$  \hspace{1cm} (1)

($C \approx 6 \cdot 10^{-13}n_e$ and $S \approx 1.3 \cdot 10^{-9}B^2\sin\alpha$ define collisional and synchrotron losses, respectively, for an electron with pitch angle $\alpha$ in ambient electron density $n_e$). We assume a power-law for the initial electron energy distribution

$$N(\gamma) = N_0(\delta - 1)(\gamma_1 - 1)^{\delta-1}(\gamma - 1)^{-\delta}$$  \hspace{1cm} (2)

with $\gamma_1$ (Lorentz factor) arbitrarily set to 1.02 and $N_0$ being the total number of nonthermal electrons above $\gamma_1$ per unit solid angle in velocity space (isotropic pitch angle distribution assumed). The temporal evolution of the electron distribution can be expressed analytically (e.g., Chiuderi-Drago & Franciosini 1993). One has to integrate the total spectral power $P(\nu, \gamma, \alpha)$ emitted by a single electron of energy $\gamma$ over the energy distribution and $4\pi$ solid angle:

$$\epsilon(\nu, t) = 2\pi \int_0^\pi \int_{\gamma_1}^{\gamma_2} P(\nu, \gamma, \alpha)N(\gamma, t)d\gamma\sin\alpha d\alpha$$  \hspace{1cm} (3)

(see Melrose 1980 for $P$; $\gamma_1 = 1.02$, $\gamma_2 = 100$ as fixed limits).

Fig. 1 illustrates characteristic decay times for a grid of $B$ and $n_e$ values. We require that the magnetic pressure considerably exceeds the gas pressure, $B^2/8\pi > 10 \cdot 2nkT$, and therefore consider the area above the diagonal only. The emission decays to $1/e$ of the peak after one characteristic decay time.
Figure 2. Fit of model lightcurve to the decaying 8.4 GHz flare portion on Sept. 21, 1994, using $\delta = 3$. The decay times are 3.2–4 hrs after removal of a constant 3 mJy background (pre-burst) level.

Since decay times varied between $\sim 0.4$ and 24 hrs, we find a range of possible trap parameters $B$ and $n_e$ (Fig. 1). A well-suited pair of observations is shown in Fig. 2. Here, the model fit requires a confined range of parameters shown in Table 1. The total kinetic electron energy per injection event is computed from the observed luminosity; it may exceed the total emitted X-ray energy during soft X-ray flares (see Güdel et al. 1995) by up to two orders of magnitude. Future observations of the power-law index $\delta$ may clarify this point. Also, broken power-laws, not assumed here, may be more appropriate toward lower energies.

<table>
<thead>
<tr>
<th>$\delta$</th>
<th>$B$ (G)</th>
<th>$n_e$ (10$^8$ cm$^{-3}$)</th>
<th>Mag. pressure/ gas pressure$^a$</th>
<th>log(kinetic energy above 10 keV) (erg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>55–40</td>
<td>2–4</td>
<td>60–220</td>
<td>32.7–32.9</td>
</tr>
<tr>
<td>3.0</td>
<td>45–20</td>
<td>2–5</td>
<td>10–150</td>
<td>33.9–34.3</td>
</tr>
<tr>
<td>3.5</td>
<td>30–15</td>
<td>2–3</td>
<td>10–65</td>
<td>35.2–35.8</td>
</tr>
<tr>
<td>4.0</td>
<td>20–15</td>
<td>3–4</td>
<td>10–20</td>
<td>36.1–36.5</td>
</tr>
</tbody>
</table>

$^a$Required to be $\geq 10$

Acknowledgments. The VLA is a facility of the National Radio Astronomy Observatory, which is operated by Associated Universities, Inc., under cooperative agreement with the US National Science Foundation.

References

Güdel, M. 1995, this volume