Extension of the Radio Spectrum of AE Aqr to the Sub-millimetric Range

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1 Introduction

AE Aquarii is a magnetic cataclysmic variable containing a white dwarf and a K3-K7 star which lies slightly above the main sequence. The white dwarf is the most rapidly rotating known ($P_{\rm rot} \simeq 33.08$ s, Patterson 1979), and it is the most strongly asynchronous with its revolution ($P_{\rm orb} = 9.88$ hr). The white dwarf accretes matter from the K star, which approximately fills the Roche lobe. AE Aqr exhibits flares in the soft X-rays, the ultra-violet, and almost continuously in the visible and the radio regimes. Rapid optical and TeV γ-ray bursts have also been discovered, which are modulated with the period of the white dwarf and at half of this period (de Jager & Meintjes 1993). This modulation, also found in X-rays, is interpreted as the accretion of matter onto the white dwarf's magnetic poles. The strength of the white dwarf's magnetic field is not well-determined, it is estimated to be $\sim 6.10^4 - 10^5$ G (Lamb & Patterson 1983, Cropper 1986) at the white dwarf's surface. Eracleous et al. (1994) recently suggested that the magnetic dipole axis lies close to the equatorial plane ($\sim 20^\circ$). De Jager et al. (1994) discovered a rapid spin down of the white dwarf leading to a spin down power which exceeds the accretion power. They suggest that a significant fraction of the spin down power may be converted to the acceleration of particles, which may explain the radio and the γ-ray emissions. Both the characteristics of the optical flares and the existence of TeV γ-rays suggest a relation with the non-thermal radio flares.

AE Aqr was discovered by Bookbinder & Lamb (1987), and by Bastian et al. (1988, hereafter BDC) as a strong radio source from 1.4 to 22.5 GHz (21 to 1.3 cm), highly variable on time scales of minutes, hours, and days. BDC also showed that AE Aqr's time-averaged spectrum is a remarkably constant power-law increasing with frequency as $S_\nu \propto \nu^\alpha$, where $\alpha \simeq 0.35$. Similar flares were also observed at 88 GHz (3.4 mm) and AE Aqr's radio spectrum was found to increase up to 240 GHz (1.25 mm), at which the flux density was ~ 48 mJy, and $\alpha \simeq 0.35 - 0.60$ (Abada-Simon et al. 1993). A detection at 250 GHz (1.2 mm) gave ~ 24 mJy (Altenhoff et al. 1994). These results suggest that the turnover frequency is ≥ 250 GHz, maybe in the sub-millimetric range.

Assuming that the radio source is not larger than the binary separation ($\sim 2.10^{11}$ cm) the inferred brightness temperature is $T_b \geq 10^{10}$ K, implying a non-thermal emission process. The lack of circular polarization and of rapid time variations are in favour of an incoherent process. BDC argue, for several reasons, that the radio flares cannot arise from the K star.

BDC attribute the radio flares to the superposition of synchrotron radiation from "clouds" of MeV electrons which are presumably accelerated at times of disruptions of the accretion flow near the white dwarf. According to BDC, as the "plasma clouds" expand, they change from optically thick to optically thin. The initial maximum flux density corresponds to an optical thickness $\tau \simeq 1$, and to a turnover frequency ν_{m0} which decreases with time. In their model, ν_{m0} is directly related to the initial magnetic field strength B_0 in a "plasmoid". Under several assumptions, among which an energy distribution for the electrons in the form of a power-law with spectral index $\delta = 2.5$, the measurement at 230 GHz then provided $B_0 \geq 250$ G, for a source radius $r_0 \simeq 10^{10}$ cm.

From the IRAS survey, which was not sensitive enough to detect AE Aqr, one can infer that its flux density is lower than 1 Jy at 100 μm, and lower than 200 mJy at 12, 25 and 60 μm: these upper limits are too high to constrain the observed radio emission.

In this paper we report the first detections of AE Aqr at 1.1 and 0.8 mm made with the James Clerk Maxwell Telescope (JCMT, Mauna Kea, HI) a few hours after microwave observations made with the Very Large Array (VLA). These observations were performed in the frame of a coordinated multi-wavelength campaign on AE Aqr, whose main part was held around 20-21 October 1993. In Sect. 2 we report our observations, and in Sect. 3 we discuss our results.

2 Observations

2.1 Observing Techniques

Microwave observations were performed with the VLA in a time sharing mode between 4.9, 8.4, 15 and 22.5 GHz (6 to 1.3 cm) on 17 and 18 October 1993, from about 20:30 to 25:30 UT.

Millimetric observations were made at 264 and 394 GHz (respectively 1.1 and 0.8 mm), with the UKT14 bolometer of the 15 m diameter mm/sub-mm JCMT on 18 and 19 October 1993, from 05:00 to 07:30 UT. The "beam-switching" observational technique was used, i.e. the source was placed alternatingly in the signal and reference beam of the chop cycle. This provided integrated scans of $\sim 3 - 9$ min on AE Aqr.

2.2 Observational Results

At centimetric wavelengths, AE Aquarii was, as usual, detected, with flares lasting for a few 10 min to several hours. They were almost continuously present, but stronger in the second night (18-19 October 1993) than in the first night. The average flux densities at 3 and 6 cm are reported for the two nights in Fig. 1.

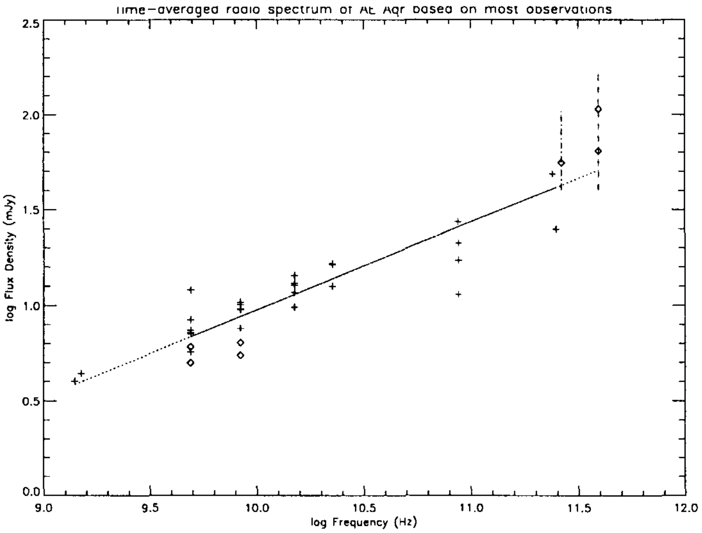

Fig. 1. Time-averaged radio spectrum of AE Aqr, based on most observations since 1984. The "+" symbols are average flux densities previously reported in the literature, and the lozenges are the values measured by the VLA and the JCMT in October 1993. The vertical dashed bars indicate the range of values measured at 1.1 and 0.8 mm with their 1-σ uncertainty.

On Mauna Kea, although the weather conditions were not good, the observations of AE Aqr made with the JCMT at 1.1 and 0.8 mm show some consistent detections, especially at 0.8 mm over the two consecutive nights. On 18 October 1993, the average flux densities at 0.8 and 1.1 mm were respectively 107.2 mJy (3.5σ) and 55.8 mJy (3.7σ), and on 19 October, an average value of 64.3 mJy (4.5σ) was obtained at 0.8 mm. These values are plotted in Fig. 1, with a vertical (dashed) "error" bar indicating the uncertainties inferred from all the significant ($S/N \geq 3$) scans (minimum to maximum: 40 to 138 mJy at 0.8 mm, and 50 to 73 mJy at 1.1 mm). The inclined dotted line represents the increasing power law obtained from fitting all the plotted flux densities, which gives a spectral index $\alpha \simeq 0.46$.

3 Discussion

The uncertainties on the flux densities measured by the JCMT lie mainly above the plotted power law line; it is clear that the turnover frequency of AE Aqr's radio spectrum is higher than 394 GHz. Applying BDC's model with all their hypotheses, we find that the initial magnetic-field strength in a plasmoid of radius $r_0 \simeq 10^{10}$ cm is 270 G $\leq B_0 \leq$ 1000 G. This upper limit is inferred from BDC's estimate of the B_0–r_0 domain in which losses due to betatron deceleration dominate over radiative synchrotron losses, for a plasmoid expanding into a uniform medium with an initial velocity $v_0 \simeq 1000$ km s^{-1}. The other alternative proposed by BDC was an expansion into a stellar wind, then they find that $v_0 \simeq 200$ km s^{-1} is required; in this case, it is interesting to find out that the detections at frequencies ≥ 300 GHz infer that B_0 is restricted to ~ 300 G. These results suggest to re-investigate BDC's model with other possible values for the assumed parameters.

AE Aqr's radio flares, and more particularly its time-averaged spectrum, increasing with frequency over more than two decades, up to an unknown frequency, remain intriguing. Its emission at frequencies ≥ 400 GHz, up to the far-infrared regime, is unexplored. More sensitive observations at several mm and sub-mm wavelengths need to be performed, not only to detect AE Aqr at wavelengths shorter than 0.8 mm, but also to study its flares and their correlations with the microwave domain (the only observations of AE Aqr ever made simultaneously in these two regimes lasted for less than 2 hours). More precise investigations of the BDC model could then be made. There is no observational constraint on the source size yet. The way electrons can be accelerated also needs to be investigated quantitatively. Finally, investigating correlations of AE Aqr's radio flares with the optical and with the TeV γ-rays should also provide constraints on the radio emission process.

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