Radio Emission from AE Aquarii

Meil Abada-Simon
Sterrekundig Instituut, Postbus 80 000, NL-3508 TA Utrecht

Tim S. Bastian
National Radio Astronomy Observatory, Socorro, NM 87801, USA

Lyndsay Fletcher
Sterrekundig Instituut, Postbus 80.000, NL-3508 TA Utrecht

Keith Horne
Physics & Astronomy, Univ. of St. Andrews, KY16 9SS, UK

Jan Kuijpers, Danny Steeghs
Sterrekundig Instituut, Postbus 80.000, NL-3508 TA Utrecht

Jay A. Bookbinder
Smithsonian Astrophysical Observatory, Cambridge, MA 02138, USA

Abstract. We present the most up-to-date knowledge and questions regarding AE Aquarii’s radio emission. A possible acceleration process for the radio-emitting particles, magnetic pumping, is proposed.

1. Introduction

AE Aquarii contains one of the most rapidly spinning white dwarfs and is the most highly asynchronous binary known ($P_{\text{spin}} \simeq 33.08 \text{ s}$, $P_{\text{orb}} = 9.88 \text{ hr}$). It exhibits flares at all wavelengths. Simultaneous optical and radio observations of AE Aqr on 2nd and 3rd June 1988 suggest that, in spite of their similarities, the flares in the two domains are due to two independent processes. In addition, their pattern of radiation is not strongly directed toward any preferred direction in the rotating frame of the binary (Abada-Simon et al. 1995a).

Bastian, Dulk and Chanmugam (1988, hereafter BDC) argue that, for several reasons, it is unlikely that the radio flares, observed from 21 cm to 3.4 mm (Abada-Simon et al. 1993), arise from the secondary. BDC interpret the radio flares as the superposition of synchrotron radiation-emitting “plasma clouds” which, as they expand, change from optically thick to optically thin. In their model, BDC could produce a power-law for the time-averaged radio spectrum, the slope of which depends on the flare frequency distribution. The average
of all non-simultaneous observations show that $S_\nu \propto \nu^\alpha$, with $\alpha \simeq 0.35$, up to an unknown frequency. During a multi-wavelength campaign on AE Aqr in October 1993, it was established that this spectrum extends at least to 0.8 mm (Abada-Simon et al. 1995b). The radio emission shows no sign of the presence of coherent oscillations at the white dwarf's spin period, or QPOs (Bastian, Beasley & Bookbinder 1995).

On the other hand, a few intriguing dips of the radio flux have been discovered in the 10 s resolution data of 2nd and 3rd June 1988: in $\sim 10 - 20$ s, AE Aqr becomes undetectable for $\sim 60$ s, and then returns to its former level in $\sim 10 - 20$ s (Abada-Simon et al. 1995a).

2. Discussion

It is plausible that these radio flux absorptions are caused by the gas blobs accreted from the secondary star. Since their velocity is $\leq (2GM_{wd}/R_{wd}^5)^{0.5} \simeq 5 \times 10^8$ cm/s (the free-fall velocity at the white dwarf's surface), the dips provide the first direct observational constraint on the (transverse) radio source size: $< 10^{10}$ cm. The inferred brightness temperature is $T_b > 10^{12}$ K. This high value suggests that the emission is synchrotron radiation emitted by electrons of energy $\simeq 100$ MeV rather than 3-30 MeV as suggested by BDC, or, alternatively, that the emission is coherent. Further, the trapped fast particles are expected to produce coherent emission via a loss-cone instability. At a distance of $10^{10}$ cm from the white dwarf, the gyrofrequency is 28 MHz - 2.8 GHz and the loss-cone instability can lead to an observable cyclotron maser (Melrose et al. 1984) or a synchrotron maser (Zheleznyakov 1967, Louarn et al. 1987), the latter in case of relativistic electrons. However, AE Aqr's radio emission characteristics (very wide bandwidth, rather slow time variations, no polarisation) are not typical of coherent emission, unless the radio flares are actually composed of (fast) narrow band components.

3. The Origin of the Radio Flares

We now present investigations by Kuipers et al. (1995) on the possible acceleration mechanism of synchrotron-radiating electrons. In AE Aqr, the white dwarf's surface magnetic field is estimated to be $10^4 \leq B(G) \leq 10^6$, and its inclination to the rotation axis is $\sim 70^\circ$ (Eracleous et al. 1994). The light-cylinder radius (distance of the furthest closed field line) is beyond the Lagrangian L1 point of the system, so that the white dwarf's field lines are compressed and decompressed every 33 s as they "encounter" the secondary star which fills in its Roche lobe. The fast moving magnetosphere can also be perturbed by the diamagnetic blobs accreted from the secondary.

As a result, the particles trapped in the white dwarf's field can be accelerated by the magnetic pumping process (see e.g. Pacholczyk 1974, Kirk 1994). This is a stochastic acceleration mechanism based on the conservation of the first adiabatic invariant ($\frac{1}{2}\gamma^2 v^2 = const.$, where $\gamma$ is the particle Lorentz factor). An increase $\Delta B$ of the magnetic field magnitude $B$ thus results in an increase of $p_\perp (= \gamma v_\perp)$, the momentum component perpendicular to $B$. If, in addition,
particles scatter (either by collisional or collisionless mechanism), then part of the energy gained in the perpendicular component is moved into the parallel component. A subsequent decrease $\Delta B$ of the field strength will thus result in a loss of only part of the perpendicular energy initially gained. The result is a net gain in the particle's energy. It is important to say that acceleration (rather than heating) occurs for non-collisional scattering (or anomalously scattering). Simulations performed under realistic hypotheses show that magnetic pumping in the presence of non-collisional scattering is efficient enough to accelerate particles (in $\sim 10^3$ s or maybe less) until their total energy becomes comparable to the magnetospheric field energy. An MHD instability then sets in and the particles are expelled from the magnetosphere in the form of expanding plasmoids whose electrons radiate synchrotron emission, thus causing the radio flares. The steady quiescent/flickering radio emission could be explained by synchrotron radiation from the particles while they are "being accelerated" by the magnetic pumping process, i.e. before the MHD instability sets in.

References

Bastian, T.S., Beasley, A.J., & Bookbinder, J.A. 1995, this volume
Zheleznyakov, V.V. 1967, Soviet Phys. JETP, 24,381