e-EVN Observations of AM Herculius

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AM Herculis is the prototype of the class of magnetic cataclysmic variables called Polars. We conducted an astrometric survey of AM Her with the e-EVN at 5 GHz in years 2012–2013, and made a new distance estimation (88.4 ± 1.5 pc). We were able to detect the AM Her quiescent radio emission in the range 0.18–0.37 mJy. We also present evidence that the AM Her quiescent radio flux is modulated with orbital phase of the system with two minima detected. We suggest that an emission mechanism similar to proposed for RS CVn binary systems could explain observed properties of the AM Her phased radio light curve. In this picture both components are magnetically active and the quiescent radio emission distinguish this kind of binary system from other Polars.

Keywords: VLBI, Astrometry, magnetic cataclysmic variables, AM Herculis.

1 Introduction

Cataclysmic variable stars are a broad class of binary systems that consist of two components: a white dwarf primary and a mass transferring secondary low-mass star. Among these object there can be distinguished a subclass of the magnetic cataclysmic variable stars (mCV), also called polars. Polars consist of a synchronously rotating with the orbital motion magnetic white dwarf and a red dwarf, which filled the Roche sphere and is losing matter via L1 point. Because of the strong magnetic field of the primary (10–230 MG) the matter cannot form accretion disk but travel along the magnetic field lines and flows onto its magnetic poles. Polars shows an irregular luminosity variability on time-scales from days to months. As polars have no accretion discs therefore changes in luminosity are connected to variations in the mass-transfer rate from the secondary. These systems are frequently studied as they exhibit a variety of physical phenomena.

Radio detections of selected mCV stars are documented in the literature. Variable radio emission at level of ~ 1 mJy was reported in case of polars AM Her, V834 Cen, AR UMa and ST LMi (e. g. [3]). The detected quiescent emission of is probably due to gyrosynchrotron radiation from ~ 500 keV electrons in the white dwarf magnetosphere [3]. Radio flaring arises most likely in a cyclotron maser operating at the surface of the red dwarf or plasma oscillations, because the emission is 100 % circularly polarized and possess a high brightness temperature ($\gtrsim 10^{10} K$).

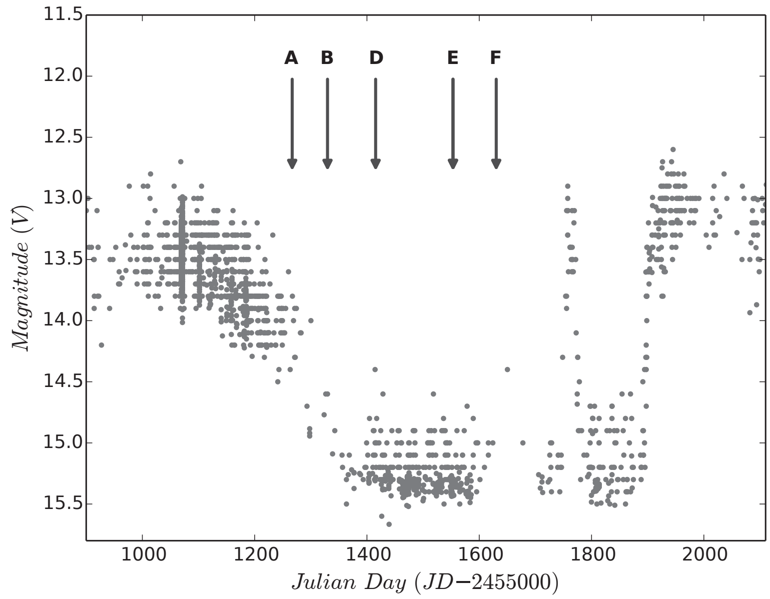

Fig. 1. The optical light-curve af AM Her during 2012–2013. Observations are provided by American Association of Variable Star Observers (*AAVSO*, http://www.aavso.org). The epochs of the e-EVN observations are indicated by arrows

AM Her is a prototype of polars and the first discovered member of the polar class. The magnetic field strength was derived 14.5 MG for the primary component [1]. This system was also the first to be detected as a radio source [2]. AM Her was observed to exhibit non–thermal emission in the range $\sim 0.3 - 0.7$ mJy [2] as well as a single 100 % circularly polarized flare (9.7 mJy, [3]), both at C–band.

2 Observations and data reduction

The interferometric observations of AM Her at a frequency 5 GHz were carried out in 5 epochs spread over 12 months from 2012 December 5 to 2013 December 3. We used the European VLBI* Network (EVN) in the e-VLBI mode of observations with the phase-referencing technique and 1 Gbs recording rate. The stations from Effelsberg, Jodrell Bank (MkII), Medicina, Noto, Onsala, Toruń, Yebes and Westerbork (phased array) participated in our observations (observing proposal code EG069). The fourth epoch was separated into two parts due to time allocation and both segments were treated as separated epochs during the reduction of data. The observation details of the all epochs are summarized in Tab. 1 . It should be mentioned that observations were performed during the decline of the optical activity (blocks A & B) and the optical low-state of AM Her (blocks D, E & F). Fig. 1 presents epochs of e-EVN observations in comparison to the AM Her optical light-curve.

*VLBI — Very Large Baseline Interferometry

Table 1

The observational log of our astrometric survey

Project code	Date [day]	[UT]	AM Her $S_{5\mathrm{GHz}}$ [μJy]
EG069A	2012 Dec 5	07:06 – 09:47	292 ± 39
EG069B	2013 Feb 6	04:37 – 07:26	371 ± 34
EG069D	2013 May 2/3	21:28 – 00:20	244 ± 29
EG069E^a	2013 Sep 17	12:10 – 13:57	178 ± 32
EG069E^b	2013 Sep 17	21:11 – 23:56	347 ± 31
EG069F	2013 Dec 3	16:38 – 19:05	297 ± 35

The whole data reduction process was carried out using standard NRAO AIPS* procedures. Maps of the phase calibrator J1818+5017 were created with the self-calibration in phase and amplitude performed and used as a model for final fringe-fitting. Task IMAGR was used to produce the final total intensity images with natural weighting of all observed sources. AM Her appears point-like on our radio map. Radio fluxes and estimated positions of all observed targets were then measured, by fitting Gaussian models, using AIPS task JMFIT. We were also able to track AM Her flux variability using the task DFTPL with an averaging interval equal to the length of individual scans.

3 Discussion

In order to determine the AM Her parallax and components of the proper motion, we apply a 5-element astrometric model (α_0, δ_0 — the target's ICRF coordinates, (μ_α, μ_δ) — components of the proper motion and π — the parallax). To improve the estimation of the AM Her proper motion, we added two archival observations from VLA. To get rid of (α, μ_δ) and (δ, μ_δ) correlations, we choose the initial epoch t_0 as the mean of all observational epochs weighted by uncertainties ($t_0 = JD\,2456457.5$). We performed our calculations with the use of the Markov Chain Monte Carlo (MCMC) technique and determined the posterior probability distribution of the astrometric model parameters. To perform the MCMC analysis, we used the affine-invariant ensemble MCMC sampler [5] encoded in the emcee package [6]. Our new parallax estimation 88.4 ± 1.5 pc ($\pi = 11.31 \pm 0.19$ mas) is in agreement with previous distance estimation based on direct parallax measurement in the optical domain (79^{+8}_{-6} pc, [8]) and theoretical so-called the K-band surface-brightness method (91^{+18}_{-15} pc, [4]).

Due to the quality of the e-EVN observations we were able to track changes in the AM Her radio flux on short ~ 5 min time-scale. We did not detect any radio flares and observed only the quiescent component in the range 180–370 μJy, which slowly varied on time-scales of hours/days. We also were able to build the AM Her phased radio light curve, which is presented on Fig. 2. We detected two minima in the light curve, a sharp one at orbital phase $\phi \simeq 0.1$ and a wider one at $\phi \simeq 0.5$.

*http://www.aips.nrao.edu/index.shtml

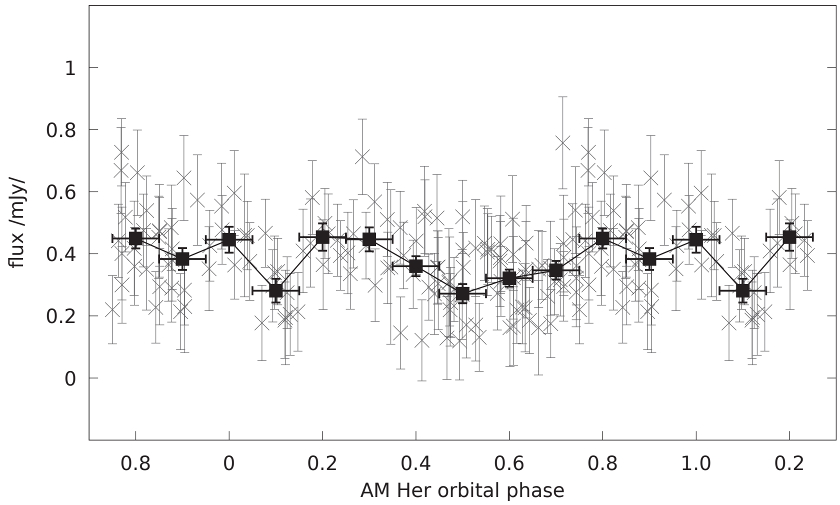

Fig. 2. The AM Her radio flux variability phased with the orbital motion of the system. Squares represent binned data, and crosses measurements for individual scans, respectively. Two minima are visible in the phased radio light curve

This observational result is in a contradiction to proposed model of AM Her radio emission, which assumes that the emission region is comparable/larger than the physical size of the binary [3]. The new e-EVN data clearly suggest that there is a correlation between the observed radio flux and the AM Her orbital phase. Moreover, the light curve is similar to observed in V471 Tau [7], a pre-CV eclipsing binary with orbital period 12.51 hr. It was postulated that an emission mechanism similar to proposed for RS CVn binary systems could explain observed radio properties of V471 Tau, where the gyrosynchrotron emission originates from ~ 400 keV electrons near the secondary surface [7]. The electrons are trapped in wedge-like magnetic structures connected to acceleration region. The acceleration is most likely caused by interaction between magnetic fields of both components, which is a result of the different rotation of primary and secondary component in V471 Tau [7]. This hypothesis requires that the secondary red dwarf posses strong magnetic field ~ 5 kG. If the V471 Tau radio emission model is applicable to AM Her the detection of the quiescent emission component could strongly indicate that the red dwarf is also magnetically active. This secondary component attribute could distinguish AM Her from other polars, where no quiescent emission was detected. However, rotation of both AM Her components is synchronized with the orbital motion and the acceleration process is different than proposed for V471 Tau.

4 Conclusions

In this work we present results from our e-EVN astrometric survey dedicated to AM Her. We made a new estimation of the annual parallax of this very interesting, active compact binary system ($\pi = 11.31 \pm 0.19$ mas, $d = 88.4 \pm 1.5$ pc). The new value of the distance to AM Her is in an agreement with previous results. We also obtained the phased radio light curve of AM Her at 6 cm. The light curve indicates that AM Her radio flux is likely modulated with the orbital phase what cannot be explained using current model of AM Her quiescent radio emission. We suggest that AM Her radio properties could be explained by the emission mechanism similar to proposed for RS CVn binary systems, where both components are magnetically active.

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