

Simultaneous UBVRI Observations of the AE Aquarii Blobs

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Abstract

We summarize the results of our study of the cataclysmic variable AE Aqr on the basis of simultaneous *UBVRI* observations. For the flares, we estimated the average risetime of about 300 sec, and colours $(U - B)_0 \sim 1.1$ and $(B - V)_0 \sim 0.1$. We also calculated temperatures, sizes, masses and expansion velocities of a few individual fireballs. In a single night (16.08.2012), we detected ~ 8 min quasi-periodic modulation.

Keywords: Stars: individual: AE Aqr - novae, cataclysmic variables - binaries: close - Stars: flare.

1 Introduction

AE Aquarii is a fascinating magnetic cataclysmic variable (CV) with orbital period of 9.88 h. Like the typical CVs, it consists of a K4 IV/V star which transfers material toward a magnetic fast spinning white dwarf (WD). AE Aqr has a relatively long orbital period and is one of the largest CVs having semimajor axis $a = 2.33 \pm 0.02 R_\odot$, WD mass $M_{WD} = 0.63 \pm 0.05 M_\odot$, secondary mass $M_2 = 0.37 \pm 0.04 M_\odot$ (the quantities obtained with high-dispersion time-resolved absorption line spectroscopy by Echevarría et al. 2008). A review of AE Aqr was presented by P. Meintjes (this volume).

AE Aqr has radio and millimeter synchrotron emission (Bastian, Dulk & Chanmugam 1988), and could be source of TeV γ -rays (Oruru & Meintjes 2012 and references therein). However, MAGIC does not detect γ -ray emission from AE Aqr (Aleksić et al. 2014). Wynn, King & Horne (1997) demonstrated that the WD is acting as magnetic propeller and is ejecting most of the matter transferred through the inner Lagrangian point in the form of blobs ('fireballs'). The *SPITZER* infrared spectrum above $12.5 \mu\text{m}$ can be interpreted as synchrotron emission from electrons accelerated to a power-law distribution in expanding clouds (Dubus et al. 2007).

AE Aqr hosts a rapidly rotating white dwarf. Its spin period is $P = 33.08$ s and spin down rate $-5.64 \times 10^{-14} \text{ s s}^{-1}$ (Patterson 1979, Mauche et al. 2011), corresponding to a spin-down luminosity of $6 \times 10^{33} \text{ erg s}^{-1}$. A part of this spin-down power goes for ejection of the blobs. The magnetospheric propeller is effective and only a small fraction ($\sim 3\%$) of the transferred material eventually accretes on to WD (Oruru & Meintjes 2012).

2 Observations

Our observations of AE Aqr were started in 1998 with an electrophotometer in V-band and are now extended to simultaneous multicolour (*UBVRI*) observations with the telescopes of the National Astronomical Observatory Rozhen (2.0m RCC, 50/70 cm Schmidt and 60 cm telescope) and the Belogradchick Astronomical Observatory (60 cm telescope). The observational sessions can be summarized as follow: (i) 1998 - 1999: V-band electrophotometric observations. (ii) Aug 2010 - Aug 2011: simultaneous multicolor (*UBVRI*) CCD observations. (iii) Sep 2011 - Aug 2013: new simultaneous multicolor CCD observations. Observational methods and data reduction are described in Zamanov et al. (2012).

3 Photometric behavior

Strong flickering and flaring activity was noted by Henize (1949). On time-scales of about 10 minutes, the light curve of AE Aqr displays flares with an amplitude up to ≈ 1 mag (see Fig.1 and Fig.2). Multicolour optical photometry was performed by Chincarini & Walker (1981) in UBV bands. Later van Paradijs, van Amerongen, & Kraakman (1989), reported five-colour (in Walraven bands) observations and showed that the flares have rise time $\sim 100 - 200$ s and occur throughout the whole orbit.

In Fig.2 we plot the orbital light curve of AE Aqr using the orbital period of 0.411655530 d and the zero-orbital phase $JD_0 = 2449281.4222200$ (Casares et al. 1996). In this figure a part of our data obtained in August 2013 are shown. The quiescent flux curve is recognizable as smooth orbital variation with two maxima and two minima per orbital cycle.

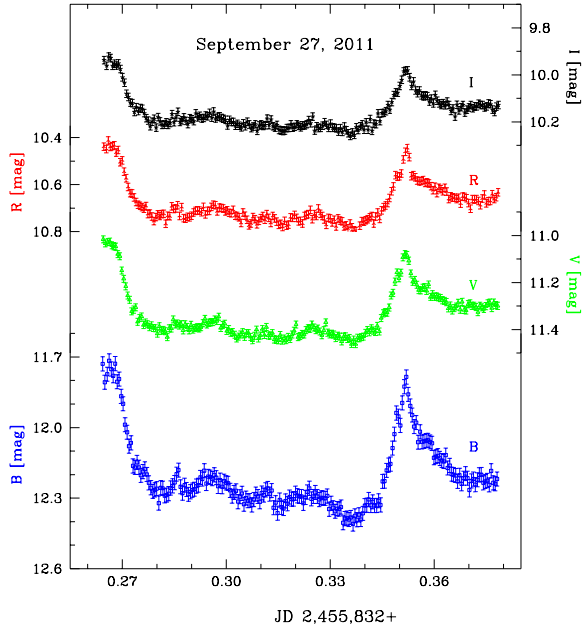


Figure 1: Optical light curve of AE Aqr obtained on September 27, 2011 in the *BVRI* bands.

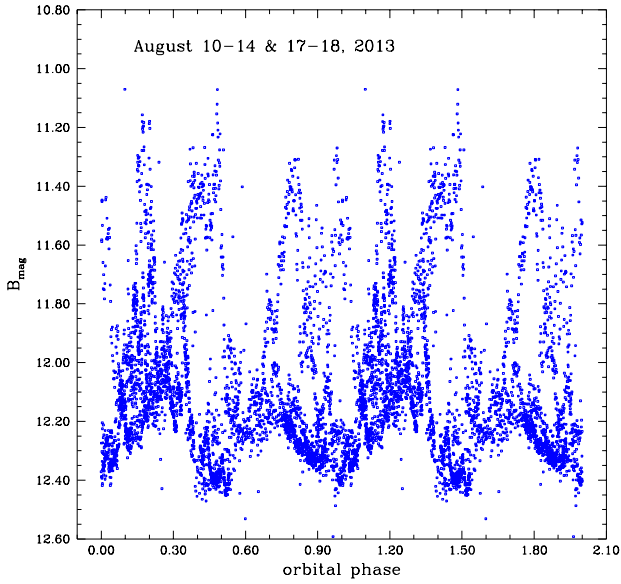


Figure 2: The *B* band light curve of AE Aqr (August 2013) folded with the orbital period (9.8797 h).

3.1 The flares as expanding fireballs

Pearson, Horne & Skidmore (2003, 2005) formulated analytic expressions for the spectral evolution and continuum light curves of flickering and flaring variability that occur over a wide range of astrophysical objects.

They applied these expressions to the observations of the cataclysmic variables AE Aqr and SS Cygni, and of the supernova SN 1987A, deriving physical parameters for the material involved. They have shown that the observed flare spectrum and evolution of AE Aqr is reproducible with an isothermal fireball with Population II abundances. The interested reader is directed to their papers for a full discussion. The basic assumptions are: (i) the flares of AE Aqr are due to the appearance and expansion of fireballs (blobs); (ii) the blobs are isothermal; (iii) they represent spherically symmetric expansion of a Gaussian density profile with radial velocity proportional to the distance from the center of the expansion.

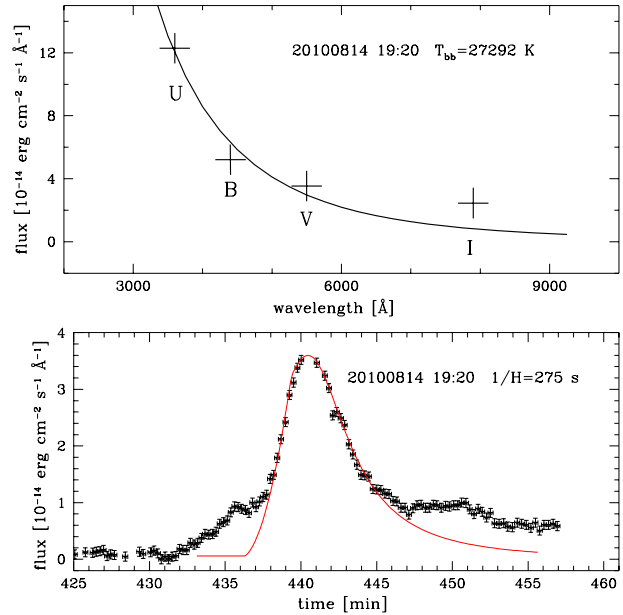


Figure 3: **Upper panel:** dereddened fluxes of a fireball at the maximum of the flare. The solid line is a black body fit. **Lower panel:** time evolution of the flare in the *V* band. The (red) solid line represents the isothermal fireball model.

Following Pearson et al. (2005), the dimensionless time β is defined as $\beta = 1 + H(t - t_{pk})$, where t_{pk} is the time of the peak of the flare, H is an “expansion constant” setting the speed of the expansion. The dimensionless time β is also the expansion factor being the constant of proportionality between the current and peak scale length a_{pk} : $\beta \equiv a/a_{pk}$. The central density of the fireball is

$$\rho = \frac{M}{(\pi a^2)^{3/2}}, \quad (1)$$

where M is the total mass of the material involved in the expansion (the fireball mass). The speed of expansion at a is $v = Ha$. The optical depth parallel to the

observer's line of sight is

$$\tau(y) = - \int_{-\infty}^{\infty} \kappa dx = \tau_0 e^{-2(\frac{y}{a})^2} \quad (2)$$

where y is the impact parameter (the distance from the fireball center perpendicular to the line of sight), κ_1 is the linear absorption coefficient, ϵ is the correction for stimulated emission, $\epsilon = 1 - e^{(h\nu/kT)}$. Here T is the fireball temperature, a is the length scale (which we call the fireball size).

The optical depth on the line of sight through the center of the fireball ($y = 0$) is

$$\tau_0 = \frac{\kappa_1 \epsilon M^2}{2^{1/2} T_0^{1/2} \nu^3 \pi^{5/2} a^5}. \quad (3)$$

The emission of the fireball is:

$$f_\nu = \frac{\pi a^2 B_\nu(T)}{2 d^2} S(\tau_0), \quad (4)$$

where $S(\tau_0)$ is the "saturation function" (see Fig. 1 of Pearson et al. 2005).

To calculate the fireball parameters T, M, a, H, ρ and v , we performed the following:

1. We compute the peak flux of the fireball, F_{pk} , in the five optical bands ($UBVRI$). An example is given in Fig.3, where the calculated peak fluxes (corrected for the reddening) are plotted.

2. We derive the temperature of the fireball with a black body approximation applying IRAF *nfit1d* routine.

3. We evaluate the size of the blob at the peak, a_{pk} , using $\tau_0 = 6.8202$ and Eq.4.

4. We calculate the mass of the fireball (Eq.3). The calculations are done adopting Population II abundances ($\kappa_1 = 1.27 \times 10^{52} \text{ m}^{-1}$).

5. Fitting the V band light curves, we derive the expansion constant H . An example is given in Fig.3 lower panel).

6. We derive the speed of expansion and the central density.

Part of the calculated parameters are given in Table 1. We reach lovely agreement between between the model and the light curves of the optical flares using fireballs with a temperature $T \sim 15000 \text{ K}$ and mass $M \sim 10^{20} \text{ g}$.

Blobs are detected in two other close binaries containing white dwarfs (the recurrent nova RS Oph and the symbiotic star CH Cyg). In future it will be interting to understand is it the same mechanism (magnetic propeller), which generates the blobs.

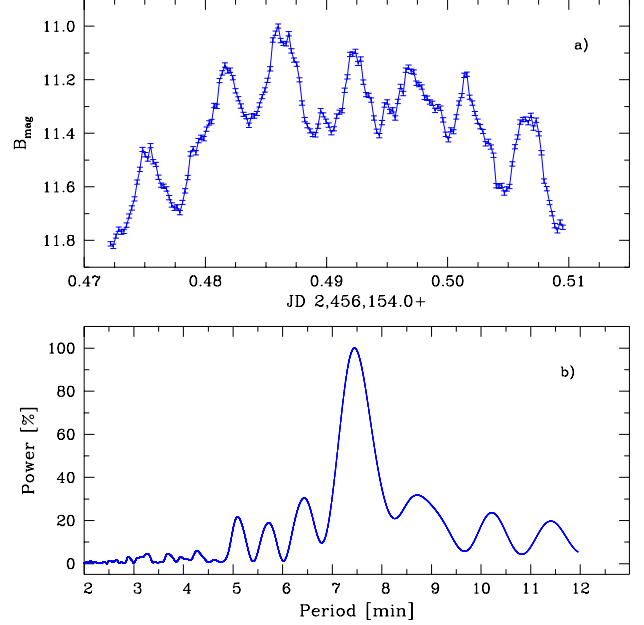


Figure 4: **a)** Light curve (in Johnson B band) of AE Aqr obtained on August 16, 2012. Quasi-periodic oscillations are visible. **b)** Power spectrum of the light curve. The maximum indicates a period of about 8 min.

4 Unusual Behaviour on August 16, 2012

Usually, AE Aqr has light curve as shown in Fig.1. However, in our observation obtained on August 16, 2012 (see Fig.4) a clear periodicity is visible. The power spectrum has a maximum corresponding to $T = 7.5 \pm 0.2$ min. Possible explanations of this unusual behavior are:

- (1) Beat modulation between the orbital period and the WD spin period (e.g. as supposed for BG CMi, Fig.7.3 of Warner 1995). The equation

$$1/P_{\text{beat}} = 1/P_{\text{spin}} - 1/P_{\text{orb}} \quad (5)$$

gives $P_{\text{beat}} = 33.03 \text{ s}$, which is too short in comparison with the observed value.

- (2) Blob rotating with Keplerian velocity at the border of the magnetosphere:

$$R_{\text{blob}} = (2\pi)^{-2/3} (GM_{\text{wd}})^{1/3} T^{2/3}, \quad (6)$$

The period $T = 7.5 \text{ min}$ corresponds to Keplerian rotation at distance $R_{\text{blob}} \approx 0.11 R_{\odot}$. The magnetospheric radius is estimated as $R_m \approx 4 - 8 R_{\text{wd}} \approx 0.05 - 0.10 R_{\odot}$ (Zamanov et al. 2012 and references therein). In our opinion, we had the chance to observe a blob rotating at the magnetosphere boundary.

Table 1: The computed parameters of the fireballs. The time is in format YYYYMMDD hh:mm. In the table are given as follows: rise time in seconds, colours of the peak emission of the fireball (corrected for the interstellar reddening), temperature of the fireball, its mass and size (at the peak of the flare).

Quantity	20100813 23:40	20100814 19:20	20100814 19:48	20100814 20:10	20110831 21:43
rise time [sec]	260±20	230±25	290±30	440±20	260±30
$(U - B)_0$	-1.36±0.06	-1.43±0.03	-0.93±0.04	-0.80±0.05	-1.02±0.07
$(B - V)_0$	0.24±0.03	0.23±0.03	0.17±0.03	0.19±0.03	0.03±0.06
temperature T [K]	14 545±1000	27 292±1500	10 856±150	9 527±100	13 395±200
mass M [10^{19} g]	9.6±1.5	6.8±1.5	39 ±6	78±12	97±15
size a_{pk} [10^9 cm]	3.0±0.3	2.5±0.3	5.3±0.3	7.1±0.4	7.7±0.4

5 Conclusions

Using 4 telescopes, we performed simultaneous observations in 5 bands (*UBVRI*) of the flare activity of the cataclysmic variable AE Aqr. Adopting the model of an isothermally expanding ball of gas, we calculated parameters (temperature, size, mass) of a few individual fireballs. In a single night, we detected ~ 8 min quasiperiodic modulation, which might be due to a blob rotating at the magnetosphere boundary.

In future we intent to measure more blobs and to search for correlations between their physical parameters. Also, we will try to do a follow-up study of the QPOs phenomenon.

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DISCUSSION

ASHLEY PAGNOTTA: What is the timescale of the short unexplained flares superimposed on the orbital modulations?

GEORGI LATEV: sampling every 10 seconds, average time from peak to peak is about 8 minutes

SIMONE SCARINGI: Given the simultaneous multi-color photometry can anything be said about color evolution of AE Aqr?

G. LATEV: We will try to do this in our future work.