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# SEARCH FOR GAMMA-RAY EMISSION FROM AE AQUARII WITH SEVEN YEARS OF *FERMI* LAT OBSERVATIONS

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## ABSTRACT

AE Aquarii (AE Aqr) is a cataclysmic binary hosting one of the fastest rotating ($P_{\rm spin} = 33.08$ s) white dwarfs (WDs) known. Based on seven years of *Fermi* Large Area Telescope (LAT) Pass 8 data, we report on a deep search for gamma-ray emission from AE Aqr. Using X-ray observations from *ASCA*, *XMM-Newton*, *Chandra*, *Swift*, *Suzaku*, and *NuSTAR*, spanning 20 years, we substantially extend and improve the spin ephemeris of AE Aqr. Using this ephemeris, we searched for gamma-ray pulsations at the spin period of the WD. No gamma-ray pulsations were detected above $3\sigma$ significance. Neither phase-averaged gamma-ray emission nor gamma-ray variability of AE Aqr is detected by *Fermi* LAT. We impose the most restrictive upper limit to the gamma-ray flux from AE Aqr to date: $1.3 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ in the 100 MeV–300 GeV energy range, providing constraints on models.

*Key words:* gamma rays: stars – novae, cataclysmic variables – X-rays: individual (AE Aquarii)

## 1. INTRODUCTION

Cataclysmic variables (CVs) are semi-detached binaries consisting of a white dwarf (WD) and a companion star, usually a red dwarf. AE Aqr is a bright ($V \approx 11$, Welsh 1999) CV, hosting one of the fastest rotating WDs known ($P_{\rm spin} = 33.08$ s, Patterson 1979) and a K 4–5 $V$ secondary; it is a non-eclipsing binary with an orbital period of 9.88 hr. Based on its trigonometrical parallax of $9.80 \pm 2.84$ mas measured with *HIPPARCOS*, the distance to AE Aqr is estimated to be $102^{+42}_{-23}$ pc (Friedjung 1997; the large errors are due to the fact that AE Aqr is very faint for a *HIPPARCOS* measurement). AE Aqr displays strong broadband variability in the radio (Bookbinder & Lamb 1987; Bastian et al. 1988), optical (Beskrovnaya et al. 1996), ultraviolet (Eracleous et al. 1995; Mauche et al. 2012), X-rays (Terada et al. 2008; Oruru & Meintjes 2012), and possibly also at TeV frequencies (Meintjes et al. 1994), though, the latter has not been confirmed. The strength of the magnetic field of the WD in AE Aqr is uncertain, but based on the typical magnetic moments of intermediate polars ($10^{32}$ G cm$^3$) and polars ($10^{34}$ G cm$^3$), it is expected to lie in the range of $B \sim 0.3$–$30 \times 10^6$ G. Specific estimates include $B \leqslant 2 \times 10^6$ G (Meintjes 2002), $B \sim 1$–$5 \times 10^6$ G (Cropper 1986; Stockman et al. 1992; Beskrovnaya et al. 1995), and $B \sim 50 \times 10^6$ G (Ikhsanov 1998).

Pulsations from AE Aqr at the spin period ($P_{\rm spin} = 33.08$ s) were first detected in the optical band (Patterson 1979), then confirmed in soft X-rays (Patterson et al. 1980), ultraviolet (Eracleous et al. 1994), and hard X-rays (Terada et al. 2008; Kitaguchi et al. 2014). Radio pulsations were searched for with the Very Large Array, but only an upper limit of 0.1 mJy was imposed (Bastian et al. 1996). The spin-down power of the WD is $\dot{E} = -I\Omega\dot{\Omega}$ ($I \approx 2 \times 10^{50}$ g cm$^2$ is the moment of inertia of the WD, $\Omega$ and $\dot{\Omega}$ are, respectively, the spin frequency and its first derivative) and is $6 \times 10^{33}$ erg s$^{-1}$ in the case of AE Aqr (de Jager et al. 1994, AE Aqr is among the few CVs where $\dot{\Omega}$ is measured). This exceeds the relatively low UV/X-ray luminosity ($L_{\rm UV} \sim L_{\rm X\text{-}ray} \sim 10^{31}$ erg s$^{-1}$) by about two orders of magnitude (see, e.g., Oruru & Meintjes 2012).

For the high magnetic field and the fast rotation period of the WD, AE Aqr has been characterized as a "WD pulsar" (e.g., Bowden et al. 1992) and has been proposed to be a particle accelerator (Ikhsanov 1998; Ikhsanov & Biermann 2006). Thus, AE Aqr could emit gamma-ray pulsations from a magnetospheric outer gap region, similar to gamma-ray pulsars (Abdo et al. 2013). Recently, the first radio pulsations in any WD systems are detected in AR Scorpii (Marsh et al. 2016) and its broadband spectrum is characteristic of synchrotron radiation, which makes AR Scorpii another "WD pulsar."

The lack of double-peaked emission lines combined with variations in line intensities associated with high velocities suggests the absence of a disk (e.g., Welsh et al. 1998). Additionally, the mass-transfer rate from the secondary star ($\dot{M} \sim 10^{17}$ g s$^{-1}$, Wynn et al. 1997) is not high enough to overcome the magnetospheric pressure. For such a mass-transfer rate, the accretion luminosity ($L_{\rm acc} = GM\dot{M}/R$, where $M$ and $R$ are the mass and radius of the WD) would be approximately three orders of magnitude larger than the observed X-ray luminosity. Thus, AE Aqr has been proposed to be in a magnetic propeller phase, ejecting most of the mass transferred from the secondary via the interaction with the magnetic field of the WD (Wynn et al. 1997). This would be consistent with the fact that the rotation velocity at the magnetospheric radius for the quoted mass-transfer rate is much larger than the Keplerian velocity (see, e.g., Oruru & Meintjes 2012).

From this point of view, AE Aqr could be a fast WD analog of the sub-luminous state of transitional pulsars in which the neutron star is surrounded by an accretion disk but is sub-luminous in X-rays with respect to accreting neutron stars (see, e.g., Papitto & Torres 2015 for a discussion), such as IGR

J18245-2452 (Papitto et al. 2013), J1023+0038 (Archibald et al. 2009; Patruno et al. 2014; Stappers et al. 2014), and XSS J12270-4859 (e.g., de Martino et al. 2010, 2013; Bogdanov et al. 2014; Papitto et al. 2015). For all of these sources, gamma-ray emission has been found, and propeller models have been developed to interpret it (e.g., Ferrigno et al. 2014; Papitto et al. 2014; Papitto & Torres 2015; Campana et al. 2016).

Gamma-ray emission from AE Aqr has been searched for at GeV and TeV energies. Using observations spanning four years (1988–1991) with the Nooitgedacht Mk I Cherenkov telescope, at an average threshold energy of ∼2.4 TeV, Meintjes et al. (1992) reported a detection of pulsating TeV emission around the WD spin period. Meintjes et al. (1994) reported simultaneous optical and TeV observations of AE Aqr and confirmed the results of Meintjes et al. (1992). TeV bursts with durations of minutes were also reported, but no pulsations were detected (Meintjes et al. 1994). Later, Bowden et al. (1992) and Chadwick et al. (1995) reported pulsating TeV emissions at the first harmonic of the WD spin period above 350 GeV with the Durham University Very High Energy telescope. A one minute long pulsating TeV burst was reported from AE Aqr by Bowden et al. (1992). However, following these early observations, campaigns with the more sensitive Whipple Observatory (Lang et al. 1998) and the MAGIC telescopes (Aleksić et al. 2014) have shown no evidence for any steady, pulsed, or episodic TeV emission of AE Aqr at any epoch. A negative result of a search for gamma-ray emission from AE Aqr in the 0.1–1 GeV band was achieved with the Compton Gamma-ray Observatory (Schlegel et al. 1995). In this paper, we report on the search for gamma-ray emission and pulsations from AE Aqr using a refined spin ephemeris of the WD in AE Aqr, using more than seven years of the latest version of *Fermi* Large Area Telescope (LAT) data.[7]

## 2. OBSERVATIONS

The *Fermi* LAT data included in this paper span seven years, from 2008 August 4 to 2015 August 7. The analysis of the *Fermi* LAT data was performed using the *Fermi* Science Tools,[8] 10-00-05 release. Events from the “P8 Source” event class (evclass = 128) and “FRONT+BACK” event type (evtype = 3) were selected.[9] The “Pass 8 R2 V6” instrument response functions (IRFs) were included in the analysis. All photons within an energy range of 100 MeV–300 GeV and within a circular region of interest (ROI) of 10° radius centered on AE Aqr were considered. To reject contaminating gamma rays from the Earth’s limb, we selected events with zenith angles <90°.

The gamma-ray flux and spectral results presented in this work were calculated by performing a binned maximum likelihood fit using the Science Tool *gtlike*. The spectral-spatial model constructed to perform the likelihood analysis includes Galactic and isotropic diffuse emission components (“gll_iem_v06.fits,” Acero et al. 2016, and “iso_P8R2_SOURCE_V6_v06.txt,” respectively[10]) as well as known gamma-ray sources within 15° of AE Aqr, based on a preliminary seven-year source list. The spectral parameters of these sources were fixed at the source list values, except for sources within 3° of our target. For these sources, all the spectral parameters were left free. In the phase-related analysis, photons within a specific phase interval are selected. To account for it, the prefactor parameter of the sources were scaled to the width of the phase interval. The test statistic (TS) was employed to evaluate the significance of the gamma-ray fluxes coming from the sources. The Test Statistic is defined as $TS = -2\ln(L_{max,0}/L_{max,1})$, where $L_{max,0}$ is the maximum likelihood value for a model without an additional source (the “null hypothesis”) and $L_{max,1}$ is the maximum likelihood value for a model with the additional source at a specified location. The larger the value of TS, the more likely that an additional source is needed. TS > 25 was the threshold for inclusion in the preliminary seven-year source list. TS maps in this paper are produced with the *Pointlike* analysis package (Kerr 2011).

For the X-ray timing analysis, we derived X-ray light curves using data from *Swift*, *Suzaku*, and *NuSTAR*. For the *Swift*/XRT observations included in our analysis, we selected Photon Counting data with event grades 0–12 in the 0.3–10 keV energy range. Source events were accumulated within a circular region centered on the source with a radius of 30 pixels (1 pixel = 2.36 arcsec). Background events were accumulated within a circular, source-free region with a radius of 60 pixels. For *Suzaku* observations of AE Aqr, we used data sets processed with the software of the *Suzaku* data processing pipeline version 2.1.6.16. We selected data from XIS 0–3 in the 0.3–10 keV energy range. Reduction and analysis of the data were performed following the standard procedure.[11] The source photons were accumulated from a circular region with a radius of 1 arcmin. The background region was chosen in the same field of view with the same radius in a source-free region. For *NuSTAR* observations of AE Aqr, we selected data from both FPMA and FPMB in the 3–10 keV energy range. Source/background events were accumulated within a circular region with a radius of 30 arcsec centered on the source/source-free region. The data were processed and screened in the standard manner using the *NuSTAR* pipeline software[12], NuSTARDAS version 1.4.1, with the *NuSTAR* calibration database (CALDB) version 20141107.

X-ray data analysis was carried out using HEAsoft version 6.16.[13] The times of arrival of the X-ray photons were corrected to the solar system barycenter using the *Chandra*-derived coordinates ($\alpha =$ 20:40:09.185, $\delta = -$00:52:15.08; J2000, Kitaguchi et al. 2014) of AE Aqr, which have sub-arcsecond uncertainties. All times are measured in terrestrial time (TT) and the DE 200 planetary ephemeris is used.

## 3. SEARCH FOR STEADY GAMMA-RAY EMISSION

Using seven years of *Fermi*-LAT data, the *gtlike* analysis of AE Aqr yielded a TS value of 0 in the 100 MeV–300 GeV energy range: steady gamma-ray emission of AE Aqr was not detected (Figure 1, left panel). There is a TS excess beyond the assumed background model in the bottom left corner of the TS map shown in Figure 1, but it is not significant (TS < 25). We calculated a 99% confidence level (CL) flux upper limit on the

[7] A *Fermi*-LAT study of AE Aqr with an earlier data release was presented in van Heerden & Meintjes (2015).
[8] http://fermi.gsfc.nasa.gov/ssc/
[9] http://fermi.gsfc.nasa.gov/ssc/data/analysis/documentation/Pass8_usage.html
[10] http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html
[11] https://heasarc.gsfc.nasa.gov/docs/suzaku/analysis/abc/
[12] http://heasarc.gsfc.nasa.gov/docs/nustar/analysis/
[13] http://heasarc.nasa.gov/lheasoft/

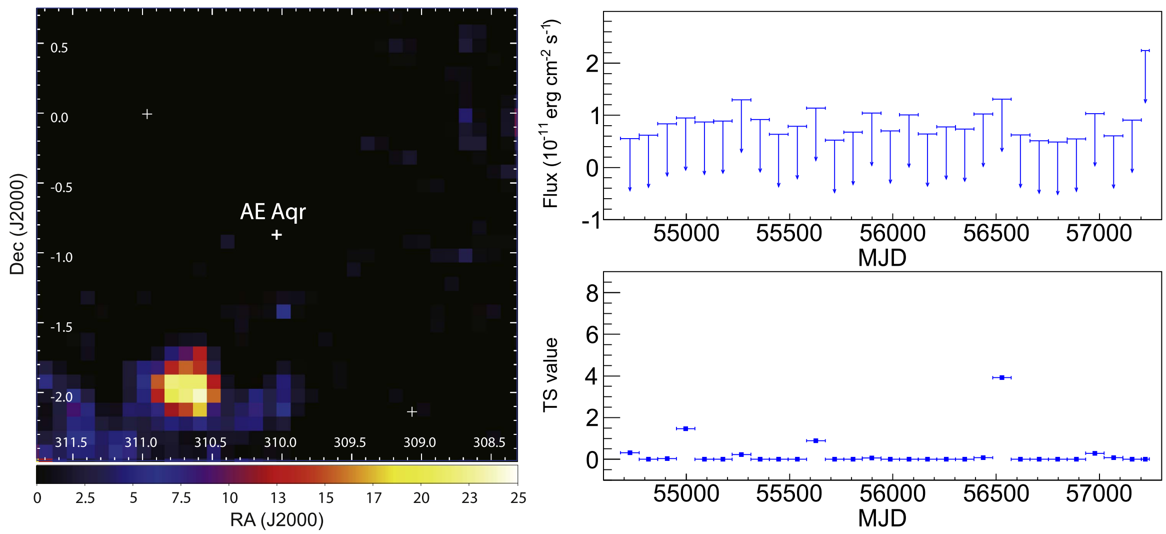


**Figure 1.** Left: TS map of AE Aqr in the 100 MeV–300 GeV energy range. The positions of AE Aqr and the sources in the preliminary seven-year source list are shown by the crosses; note that the excess in the bottom left corner of the plot has a TS $< 25$, and in any case is far from the position of AE Aqr. Right: three-month binned long-term light curve of AE Aqr. Note that the last bin only spans 39 days.

**Table 1**
X-Ray Observations and Timing Data

| Date | Observation Duration (days) | Spin-Phase Offset | Date of Pulse Maximum (MJD) | $\chi^2$/dof | Satellite |
|---|---|---|---|---|---|
| 1995 Oct | 0.82 | 0.037 ± 0.011 | 50004.2037529 ± 0.0000044 | 24.31/17 | *ASCA* |
| 2001 Nov | 0.15 | 0.146 ± 0.007 | 52221.0720142 ± 0.0000029 | 28.22/17 | *XMM-Newton* |
| 2005 Aug | 0.82 | 0.237 ± 0.010 | 53612.7767058 ± 0.0000039 | 18.53/17 | *Chandra* |
| 2005 Aug | 2.28 | 0.274 ± 0.060 | 53612.7967672 ± 0.0000229 | 1.05/3 | *Swift* |
| 2005 Oct | 2.08 | 0.225 ± 0.009 | 53673.9503081 ± 0.0000033 | 12.94/17 | *Suzaku* |
| 2006 Oct | 2.23 | 0.263 ± 0.009 | 54033.2674939 ± 0.0000036 | 25.43/17 | *Suzaku* |
| 2009 Oct | 3.46 | 0.376 ± 0.013 | 55120.7649611 ± 0.0000051 | 5.41/9 | *Suzaku* |
| 2012 May | 32.88 | 0.565 ± 0.029 | 56062.1941461 ± 0.0000110 | 3.99/7 | *Swift* |
| 2012 Sep | 2.92 | 0.537 ± 0.013 | 56174.8316376 ± 0.0000051 | 40.60/17 | *NuSTAR* |
| 2012 Sep | 0.07 | 0.521 ± 0.069 | 56176.2607899 ± 0.0000265 | 1.97/7 | *Swift* |
| 2015 Jun | 0.27 | 0.630 ± 0.041 | 57176.1997047 ± 0.0000159 | 3.00/4 | *Swift* |
| 2015 Dec | 0.49 | 0.694 ± 0.108 | 57373.0316534 ± 0.0000415 | 0.06/2 | *Swift* |

steady flux from AE Aqr of $1.3 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$, according to Helene's method (Helene 1983), assuming a photon index of 2.0 in the 100 MeV–300 GeV energy band. Systematic effects have been considered by repeating the upper limit analysis using modified IRFs that bracket the effective area and changing the normalization of the Galactic diffuse model artificially by ±6%.

By selecting photons of spin phases 0.9–1.2 (see below for details) covering periods of relatively high gamma-ray counts (details of which are provided below and in Section 4), we searched for gamma-ray emission from AE Aqr. No detection was made. A 99% CL flux upper limit of $4.4 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ is evaluated according to Helene's method (Helene 1983) in the 100 MeV–300 GeV energy range, again assuming a photon index of 2.0.

The three-month binned long-term light curve of AE Aqr is shown in Figure 1, right panel. All data points are upper limits and no flux variability is detected. To search for gamma-ray flares as short as the TeV flare reported by Meintjes et al. (1994), we extracted the photons within 0°.5 of AE Aqr and produced an exposure-corrected photometry light curve in one-minute bins. No gamma-ray flare is detected above the 1.5$\sigma$ level.

## 4. TIMING ANALYSIS OF AE AQR

Rotational phases for each photon that passed the selection criteria could be calculated using TEMPO2 (Hobbs et al. 2006) with the *Fermi* plug-in (Ray et al. 2011), and the significance of gamma-ray pulsations evaluated by the H-test (de Jager et al. 1989; de Jager & Büsching 2010). However, it is first necessary to have available a precise ephemeris of AE Aqr covering the span of the *Fermi*-LAT data. Using 14.5 years of optical data, de Jager et al. (1994) discovered that AE Aqr is spinning down at a rate of $\dot{P} = 5.642(20) \times 10^{-14}$ d d$^{-1}$. Relying on the fact that the optical and X-ray spin pulses are aligned in phase (Patterson et al. 1980), Mauche (2006) employed *ASCA*, *XMM-Newton*, and *Chandra* X-ray observations spread over 10 years to extend the baseline of observations of AE Aqr to 27 years. He found that the WD in AE Aqr is spinning down slightly faster than given by the de Jager et al. ephemeris in a manner consistent with a second derivative of the period change,

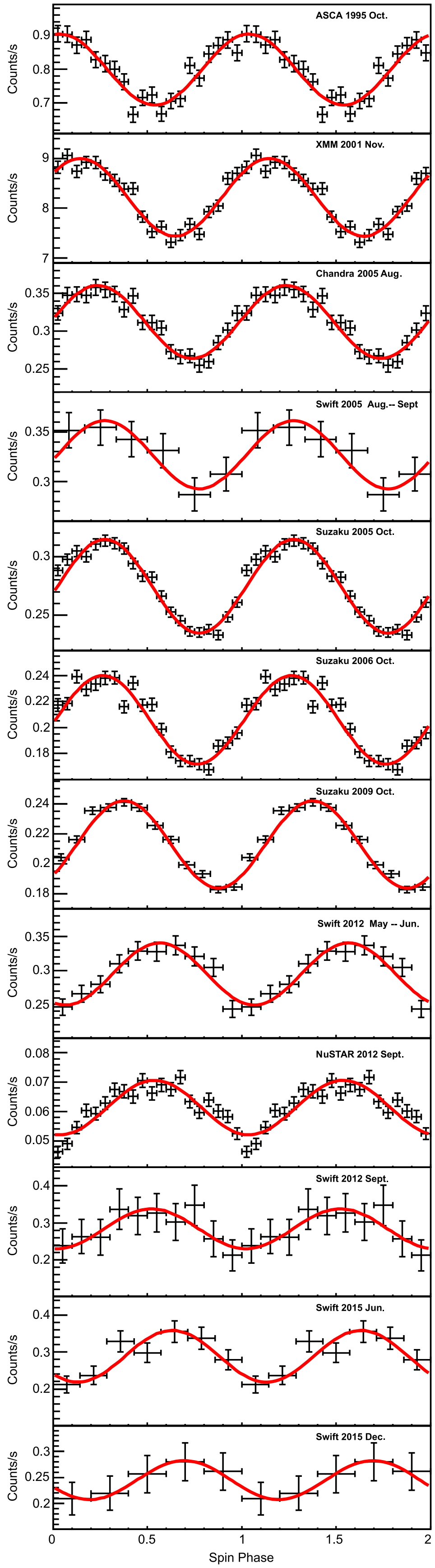


**Figure 2.** Spin-phase-folded X-ray light curves of AE Aqr as obtained by the various satellites. The *ASCA*, *XMM-Newton*, and *Chandra* light curves are taken from Mauche (2006). Two full rotations are shown for clarity. Best fitted sinusoids are shown by the solid red curves.

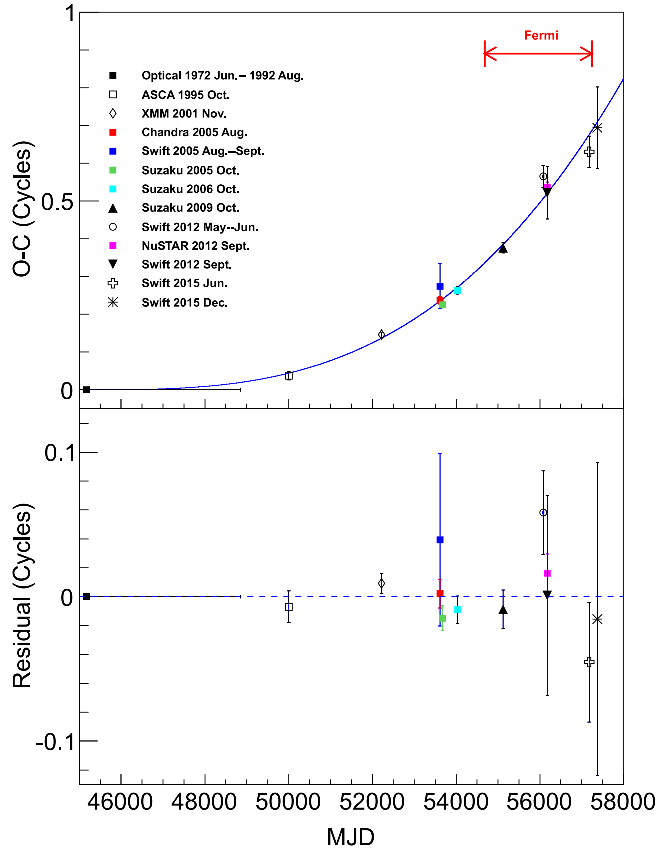


**Figure 3.** Top: spin-phase offsets (observed minus calculated spin phases) of AE Aqr from different X-ray observations as a function of time. The function fit to the data points is indicated by the blue curve. The interval of *Fermi* observations covered in this paper is shown by the red arrow. Bottom: residuals of the fitting in above panel.

$\ddot{P} = 3.46(56) \times 10^{-19}\ \mathrm{d}^{-1}$. Because the spin ephemeris is descriptive and not necessarily predictive, we added *Swift*, *Suzaku*, and *NuSTAR* observations to extend and refine the spin ephemeris of AE Aqr over the span of the *Fermi*-LAT observations (see Table 1). Due to the orbital motion of the WD around the binary center of mass, a photon arrival time delay of ∼2 s has been observed on AE Aqr at optical (de Jager et al. 1994), ultraviolet (Eracleous et al. 1994), and X-ray (Mauche 2006) frequencies. As was done by Mauche (2006), before calculating the spin phases, we corrected the photon arrival times for the $2\cos(\phi_{\mathrm{orb}})$ second delays for the orbital ephemeris of de Jager et al. (1994). We produced spin-phase-folded X-ray light curves of AE Aqr for the various satellites assuming the de Jager et al. (1994) spin ephemeris; the light curves of *ASCA*, *XMM-Newton*, and *Chandra* are adopted from Mauche (2006). Each light curve shows a similar sinusoidal profile and is fitted by a sinusoid function (Figure 2, red solid curves). The fitted $\chi^2$ values, degrees of freedom, and spin-phase offsets are listed in Table 1.

It is evident from Figure 2 and Table 1 that the values of the spin-phase offsets derived from the various X-ray observations increase with time. Figure 3 plots the spin-phase offsets versus time, demonstrating that the observed phases (“O”) diverge systematically from the calculated phases (“C”) assuming the de Jager et al. (1994) spin ephemeris. We fitted the data following the same method as Mauche (2006), yielding a new $\ddot{P} = 3.43(5) \times 10^{-19}\ \mathrm{d}^{-1}$ and a reduced $\chi^2$ of 1.14 (blue curve in Figure 3), which is consistent with, but reduces the error on,

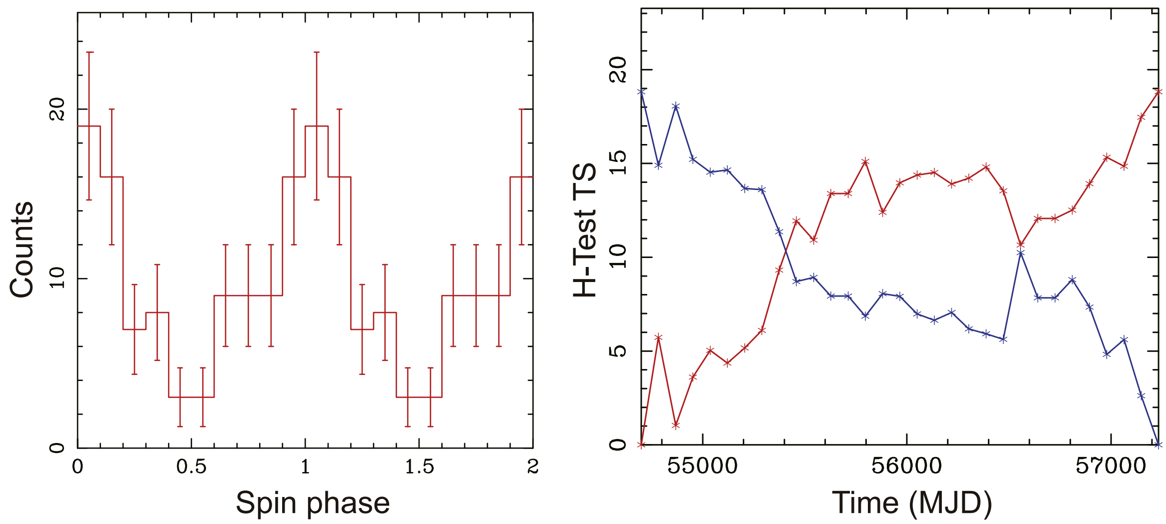


**Figure 4.** Left: gamma-ray pulse profile of AE Aqr in the 1.7–10 GeV energy range, with a ROI radius of 0°.6 folded on our timing ephemeris. Two full rotations are shown for clarity. Right: H-test TS value of AE Aqr as a function of time. The red line represents the trend of the TS value as data is accumulating from the start of the mission, while the blue line represents the same trend as data is accumulating from the end of the integration.

the $\ddot{P}$ term introduced by Mauche (2006). Thus, the spin ephemeris of AE Aqr extended for the *Fermi*-LAT data is determined as

| | | |
|---|---|---|
| Epoch | $T_0 = 45171.500042$ (barycentered MJD) | de Jager et al. (1994) |
| Spin period | $P = 0.00038283263840$ d | de Jager et al. (1994) |
| Spin period derivative | $\dot{P} = 5.642 \times 10^{-14}$ d d$^{-1}$ | de Jager et al. (1994) |
| Spin period second derivative | $\ddot{P}' = 3.43 \times 10^{-19}$ d$^{-1}$ | this paper |
| Orbital period | $P_{\rm orbit} = 0.411655610$ d | de Jager et al. (1994) |
| Time of superior conjunction | $T_0' = 45171.7784$ (barycentered MJD) | de Jager et al. (1994) |
| Projected semi-amplitude | $a_{\rm WD}$ sin $i = 2.04$ s | de Jager et al. (1994) |

Adopting this ephemeris, we searched for gamma-ray pulsations of AE Aqr via an H-test procedure, for all *Fermi*-LAT photons below 10 GeV, exploring different values of the minimum energy (from 100 MeV to 2.5 GeV in steps of 400 MeV) and radius (0°.3, 0°.6, 0°.9) from AE Aqr of the *Fermi*-LAT data. The maximum H-test TS value we obtained is 18.8 in the 1.7–10 GeV energy range with an ROI radius of 0°.6. This is a 3.5$\sigma$ result before trial corrections, but only 2.6$\sigma$ after considering the trials in minimum energy and ROI radius. The folded pulse profile and TS value as a function of time is shown in Figure 4, left and right panels. The H-test TS value shows an increasing trend as data accumulate.

We fitted a constant to the folded 1.7–10 GeV *Fermi*-LAT spin gamma-ray light curve, yielding an average flux of 6.92 ± 0.83 counts and a reduced $\chi^2$ of 29.82/9, demonstrating that the gamma-ray light curve is not consistent with being constant with spin phase. A sinusoidal function plus a constant was also fitted to the gamma-ray light curve, yielding a pulse amplitude of 6.77 ± 1.47 counts, a constant of 9.64 ± 1.12 counts, a spin-phase offset of 0.01 ± 0.03, and a reduced $\chi^2$ of 4.48/7. The F-test indicates that the fitting with a sinusoidal function plus a constant is favored over a constant fitting at 99.87% CL (~3$\sigma$). The folded 1.7–10 GeV *Fermi*-LAT spin gamma-ray light curve peaks around zero spin phase. The optical, ultraviolet, and X-ray spin pulses of AE Aqr are aligned in phase and also may be aligned with possible gamma-ray pulses if they exist just below the LAT sensitivity. However, no significant gamma-ray pulsations can be claimed at this time, because of the limited statistics. The usual threshold for gamma-ray pulsar discovery is 5$\sigma$ (Abdo et al. 2013). Assuming AE Aqr continues to follow the exact same pattern as has been shown in current *Fermi*-LAT data, the trial corrected significance of the gamma-ray pulsation from AE Aqr will reach a 5$\sigma$ level with an additional ~7.5 years of *Fermi*-LAT observations. To track the evolution of the spin period and sustain the valid spin ephemeris, regular monitoring of AE Aqr in the optical, ultraviolet, and/or X-rays, is required.

## 5. DISCUSSION

We carried out the first detailed *Fermi*-LAT data analysis of AE Aqr, searching for gamma-ray pulsations and for steady gamma-ray emission. Neither was detected. We extended and refined the spin ephemeris of Mauche (2006) using data from 12 different observations by six X-ray satellites spanning 20 years. Gamma-ray pulsations have been searched for using the extended ephemeris but no detection was made beyond a hint at the 2.6$\sigma$ significance level. We calculated a 99% CL flux upper limit on the steady emission from AE Aqr of $1.3 \times 10^{-12}$ erg cm$^{-2}$ s$^{-1}$ in the 100 MeV–300 GeV energy range. This corresponds to a luminosity upper limit of $1.6 \times 10^{30}$ erg s$^{-1}$ at 102 pc and a gamma-ray efficiency of less than $2.7 \times 10^{-4}$. No long-term flux variability is detected on a three-month basis and no flare activity was detected on timescales of one minute.

Meintjes & de Jager (2000) proposed a propeller model to explain the TeV emission reported by Meintjes et al. (1994) and Chadwick et al. (1995), assuming that the magnetic field of the WD of AE Aqr is rotating through a clumpy ring near the circularization radius. In this model, particles could be accelerated to relativistic energies by the huge potential differences in the clumpy ring, leading to a gamma-ray luminosity $\sim 10^{34}$ erg s$^{-1}$ during bursts, which is equal to the total spin-down power. The upper limits to the steady gamma-ray luminosity measured by MAGIC ($\sim 6.8 \times 10^{30}$ erg s$^{-1}$

above 200 GeV, Aleksić et al. 2014) and our present analysis in the 100 MeV–300 GeV energy range are both several orders of magnitude lower than this model prediction. It is not likely that the model proposed by Meintjes & de Jager (2000) could account for the gamma-ray emission of AE Aqr, unless the episodes of gamma-ray emission are much more sporadic than expected, an assumption that seems ad hoc and unattractive. We note that the propeller model studied for transitional pulsars such as J1023+0038 discussed above was developed to explain a gamma-ray luminosity of the order of $10^{34}$ erg $s^{-1}$, or ∼22% of the corresponding pulsar's spin-down power. The upper limit found in gamma rays is quite constraining in comparison to the spin-down power of AE Aqr (it is similar to the limit reported by MAGIC, but at gamma-ray energies that are three orders of magnitude smaller). We conclude that the rotation of the WD may be enough to preclude accretion, but not enough either to generate turbulence in the disk-field interface region, or reconnection events of the field, so that particles are accelerated up to TeV energies at a significant rate.

The particle acceleration and energy release of a fast rotating, magnetic WD could also be explained in terms of the canonical spin-powered pulsar model. With a pulsar-like acceleration process, Ikhsanov (1998) and Ikhsanov & Biermann (2006) proposed the ejector WD model (EWD) to explain the possible gamma-ray emission from AE Aqr. Applying the EWD model, the high energy emission of AE Aqr is dominated by the radiative loss of TeV electrons accelerated in the magnetosphere. Gamma-ray emission would arise from inverse Compton scattering and the luminosity would be in the relatively uncertain range of 3–500 × $10^{27}$ erg $s^{-1}$. The upper limit derived in this paper is still one order of magnitude higher, so the EWD model prediction does not conflict with our results; though, it is currently untestable.

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