

New candidates for AM Canum Venaticorum stars among ASAS-SN transients

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Abstract

We studied Zwicky Transient Facility (ZTF) light curves of 34 dwarf nova candidates discovered by the All-Sky Automated Survey for Supernovae (ASAS-SN) between 2020 May 12 and September 9 and found six AM CVn-type candidates. All objects showed short outbursts (post-superoutburst rebrightenings) on the fading tail. Two objects (ASASSN-20eq, ASASSN-20la) showed double superoutbursts. Three objects (ASASSN-20jt, ASASSN-20ke, and ASASSN-20lr) showed short superoutbursts (5–6 d). These features in the light curve can be used in discriminating AM CVn-type candidates from hydrogen-rich systems. In contrast to hydrogen-rich systems, some object did not show red color excess during the rebrightening or fading tail phase. We interpret that this is due to the higher ionization temperature in helium disks. Two objects had long (likely) supercycles: ASASSN-20gx (8.5 yr) and ASASSN-20lr (7 yr). We provide a scheme for identifying AM CVn-type candidates based on the light curve characteristics.

Key words: accretion, accretion disks — novae, cataclysmic variables — stars: dwarf novae — stars: individual (ASASSN-20eq, ASASSN-20gx, ASASSN-20jt, ASASSN-20ke, ASASSN-20la, ASASSN-20lr) — surveys

1 Introduction

AM CVn stars are a class of cataclysmic variables (CVs) containing a white dwarf (primary) and a mass-transferring helium white dwarf (secondary). [For a review of AM CVn stars, see, e.g., Solheim (2010).] In systems with mass-transfer rates (\dot{M}) the accretion disk around the primary become thermally stable and no outbursts are observed. In systems with lower \dot{M} , the disk becomes thermally unstable and dwarf nova (DN)-type outbursts occur (Tsugawa & Osaki 1997; Solheim 2010; Kotko et al. 2012). The mass transfer in AM CVn stars is driven by angular momentum loss due to the gravitational wave radiation, and \dot{M} is a strong function of the orbital period (P_{orb}). Systems with short P_{orb} (less than 22 min) have thermally stable disks and those with longer P_{orb} have thermally unstable disks

(Ramsay et al. 2012; Kotko et al. 2012). It is not yet clear whether AM CVn stars with extremely low \dot{M} have thermally unstable disks and show outbursts, but the recent discovery of an outbursting AM CVn star, ZTF20acyxwzf, with $P_{\text{orb}} = 0.0404(3)$ d (N. Kojiguchi et al. in preparation) suggests that AM CVn stars even with the longest P_{orb} have thermally unstable disks.

AM CVn stars have low mass ratios ($q = M_2/M_1$). In systems with low q , the disk becomes tidally unstable due to the 3:1 resonance (Whitehurst 1988; Hirose & Osaki 1990; Lubow 1991) and the precessing eccentric disk, the eccentricity of which is excited by the 3:1 resonance, causes superhumps and superoutbursts (Osaki 1989). In extremely low- q systems, the disk can even hold the radius of the 2:1 resonance and this is believed to be

Table 1. List of objects.

Object	Right ascension (J2000.0)	Declination (J2000.0)	Variability range	Parallax (mas)	Gaia BP	Gaia RP
ASASSN-20eq	17 ^h 35 ^m 00 ^s .45	+25°36′54″.8	15.4–21.5g	–	–	–
ASASSN-20gx	23 ^h 49 ^m 30 ^s .14	+22°01′29″.6	14.8–20.3g	1.40(52)	20.40(10)	19.91(13)
ASASSN-20jt	23 ^h 02 ^m 36 ^s .07	+53°28′22″.6	17.0–22.1g	–	20.12(10)	19.36(11)
ASASSN-20ke	18 ^h 42 ^m 17 ^s .83	+16°55′01″.3	16.1–21.0g	0.95(78)	20.89(10)	20.39(21)
ASASSN-20la	01 ^h 38 ^m 51 ^s .95	+46°34′48″.9	16.1–21.5g	–	–	–
ASASSN-20lr	04 ^h 22 ^m 20 ^s .06	+50°07′13″.0	14.6–20.0g	2.19(40)	19.83(3)	19.38(5)

responsible for the WZ Sge-type phenomenon (Osaki & Meyer 2002), which shows infrequent large-amplitude superoutbursts and often post-superoutburst rebrightenings (Kato 2015). Post-superoutburst rebrightenings in AM CVn stars are relatively commonly seen (Isogai et al. 2015a; Duffy et al. 2021).

AM CVn stars have recently received special attention and there have been a number of projects in search of AM CVn stars. Anderson et al. (2005) and Rau et al. (2010) used spectra and Carter et al. (2013) used colors in the Sloan Digital Sky Survey (SDSS). Levitan et al. (2015) used the Palomar Transient Factory (PTF) to detect outbursting AM CVn stars. High time-resolution observations also discovered several AM CVn stars [e.g., (Burdge et al. 2019, 2020) using the Zwicky Transient Facility (ZTF) data]. A number of outbursting AM CVn stars have been identified by time-series observations to search for superhumps (e.g., Kato et al. 2015b; Isogai et al. 2015a, 2019). Most recently, van Roestel et al. (2021) selected ZTF transients by colors and detected several new AM CVn stars.

In this paper, we present new candidate AM CVn stars from potential dwarf novae (DNe) recently detected by the All-Sky Automated Survey for Supernovae (ASAS-SN; Shappee et al. 2014; Kochanek et al. 2017).¹ using the public light curves of the ZTF survey (Masci et al. 2019).² We supplemented the data using the Asteroid Terrestrial-impact Last Alert System (ATLAS) Forced Photometry (Tonry et al. 2018).³ The list of object is shown in table 1. The coordinates and variability range are taken from the American Association of Variable Star Observers’ Variable Stars Index (AAVSO VSX).⁴ The parallaxes and quiescent magnitudes are taken from Gaia EDR3 (Gaia Collaboration 2021).

¹ The list of ASAS-SN Transients is available at (<http://www.astronomy.ohio-state.edu/assassin/transients.html>).

² The ZTF data can be obtained from IRSA (<https://irsa.ipac.caltech.edu/Missions/ztf.html>) using the interface (https://irsa.ipac.caltech.edu/docs/program_interface/ztf_api.html) or using a wrapper of the above IRSA API (<https://github.com/MickaëlRigault/ztfquery>).

³ The ATLAS Forced Photometry is available at (<https://fallingstar-data.com/forcedphot/>).

⁴ (<https://www.aavso.org/vsx/>).

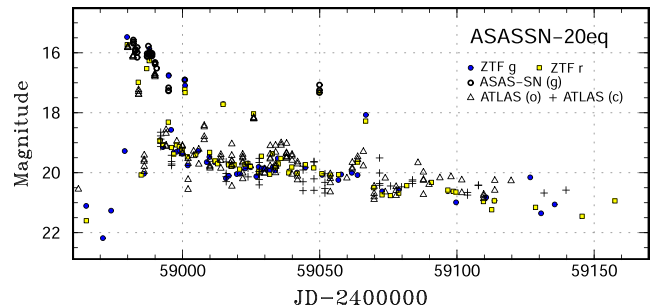


Fig. 1. Light curve of ASASSN-20eq. The filled squares and circles represent ZTF *r* and *g* observations, respectively. Open circles, triangles, and “+” signs represent ASAS-SN, ATLAS *o*, and ATLAS *c* observations, respectively. (Color online)

2 Individual objects

2.1 ASASSN-20eq

This object was detected at $g = 15.6$ on 2020 May 12. We noticed that this object showed multiple rebrightenings on a fading tail from ZTF observations. The quiescent color in SDSS is unusual in that the object had a strong ultraviolet excess of $u - g = -0.22$ (vsnet-alert 25852).⁵ Using ATLAS and ASAS-SN observations, D. Denisenko (vsnet-alert 25859) and P. Schmeer (vsnet-alert 25861) identified the initial superoutburst.

The combined light curve (figure 1) shows two superoutbursts (JD 2458979–2456984 and JD 2458986–2458991) separated by fading. Six post-superoutburst rebrightenings were detected in the available data.

The overall light curve is very similar to that of the “double superoutburst” of AM CVn star NSV 1440 (Isogai et al. 2019). Very rapid fading (more than 2 mag d^{-1}) of rebrightenings is also characteristic of AM CVn-type outbursts [the Bailey relation for hydrogen-rich dwarf novae—that the decline rate T_{decay} is proportional to $P_{\text{orb}}^{0.79}$ (Warner 1987, 1995)—has been confirmed to apply to AM CVn stars (Patterson et al. 1997)]. Based on these characteristics

⁵ The vsnet-alert messages can be seen at (<http://ooruri.kusastro.kyoto-u.ac.jp/pipermail/vsnet-alert/>).

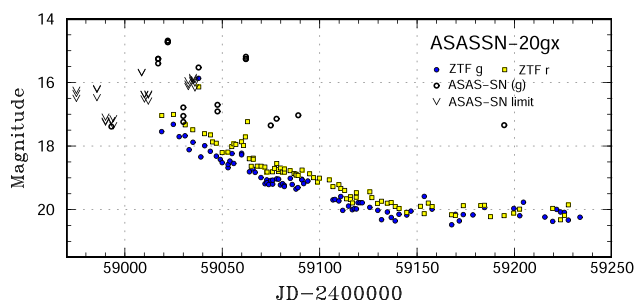


Fig. 2. Light curve of ASASSN-20gx. The filled squares and circles represent ZTF r and g observations, respectively. Open circles and “v” marks represent ASAS-SN observations and upper limits, respectively. (Color online)

of the light curve and a strong ultraviolet excess, we identified this object to be an AM CVn star. The initial superoutburst was most likely characterized by the 2:1 resonance (Isogai et al. 2019; Kato et al. 2014) and the second one almost certainly showed ordinary superhumps. Based on the similarity of its light curve with that of NSV 1440, the P_{orb} of ASASSN-20eq is expected to be around 0.025 d.

2.2 ASASSN-20gx

This object was detected at $g = 15.4$ on 2020 June 16 and further brightened to $g = 14.8$ on 2020 June 21. We noticed multiple rebrightenings on a fading tail from ZTF observations as in ASASSN-20eq (vsnet-alert 25853). The light curve (figure 2) suggests that ASAS-SN observations missed the initial superoutburst during observational or seasonal gaps (maximum of a 12 d gap and the observations started just after the seasonal gap).

There were at least five rebrightenings (assuming that there was an unrecorded superoutburst). These rebrightenings showed rapid fading (2 mag d^{-1}). Combined with the blue color in quiescence ($u - g = +0.15$ in SDSS), we consider that this object is also an AM CVn star. Although we cannot completely exclude the complete absence of the initial superoutburst from the available observations, this possibility appears to be low considering the similarity of the light curve of the fading tail with those of other well-observed superoutbursts of AM CVn stars.

D. Denisenko reported another past outburst in 2011 December–2012 January (vsnet-alert 25860) in Catalina Sky Survey Data (CRTS; Drake et al. 2009). The Panoramic Survey Telescope and Rapid Response System (Pan-STARRS1; Chambers et al. 2016)⁶ also detected this outburst and CRTS probably recorded the fading tail. If there was no outburst between 2012 and 2020, the supercycle is probably around 8.5 yr.

⁶ (<https://panstarrs.stsci.edu/>).

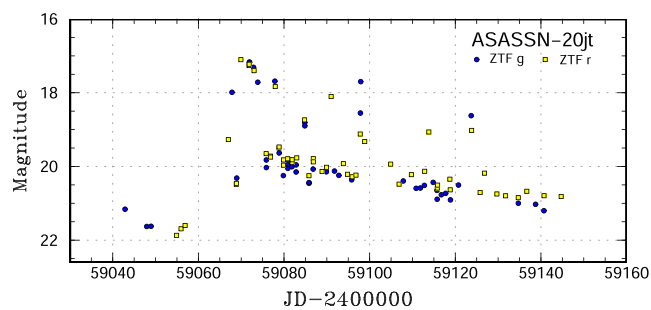


Fig. 3. Light curve of ASASSN-20jt. The filled squares and circles represent ZTF r and g observations, respectively. (Color online)

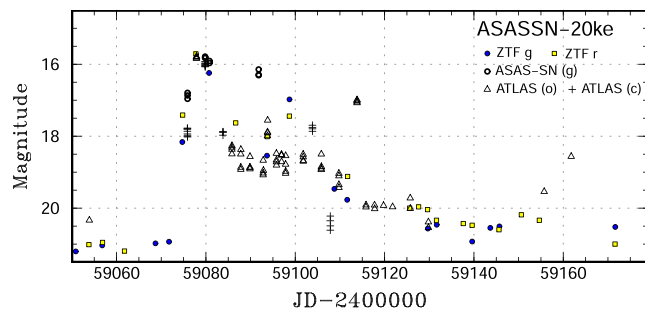


Fig. 4. Light curve of ASASSN-20ke. The filled squares and circles represent ZTF r and g observations, respectively. Open circles, triangles, and “+” signs represent ASAS-SN, ATLAS o, and ATLAS c observations, respectively. (Color online)

2.3 ASASSN-20jt

This object was detected at $g = 17.0$ on 2020 August 7. The light curve based on the ZTF data (figure 3) indicates brightening from $r = 19.27$ on 2020 August 5 (JD 2459067) to $g = 18.00$ on 2020 August 6, followed by a dip at $g = 20.32$ on 2020 August 7 (despite the ASAS-SN transient detection, no positive observation was available from the ASAS-SN Sky Patrol). After this, a long outburst lasting at least 4 d was recorded. There were six rebrightenings on a fading tail. The initial short outburst was likely a precursor and the long outburst was likely a superoutburst. Based on the short duration of the main superoutburst and rapid fading (up to 1.7 mag d^{-1}), we identified this object as a likely AM CVn star.

There was a similar, but less observed, outburst in 2018 October–December in the ZTF data. The observations only recorded the phase of fading tail and three rebrightenings were detected on it. The supercycle of this object is estimated to be ~ 670 d.

2.4 ASASSN-20ke

This object was detected at $g = 16.2$ on 2020 August 18. The light curve based on the ZTF and ASAS-SN data (figure 4) indicates the initial long outburst lasting 6 d. There was at least three confirmed post-superoutburst

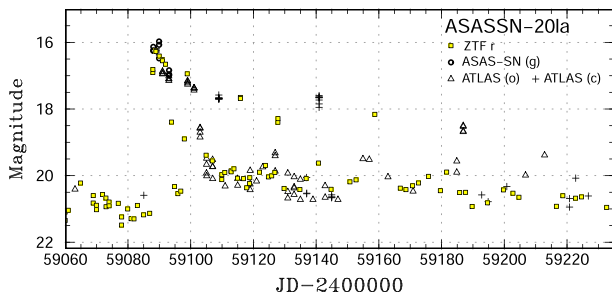


Fig. 5. Light curve of ASASSN-20la. The filled squares represent ZTF r observations. Open circles, triangles, and “+” signs represent ASAS-SN, ATLAS o , and ATLAS c observations, respectively. (Color online)

rebrightenings. Although there were several more ASAS-SN detections around $g = 17.0$, they were spurious detections near the detection limit which were confirmed by comparison with ATLAS data. These detections are not plotted on the figure. This object is most likely classified as an AM CVn star based on the short duration of the initial superoutburst and rapid fading (more than 2 mag d^{-1}) of rebrightenings.

There was another outburst in 2019 July–August. This outburst was only detected by ZTF and ATLAS and rebrightenings on a long-lasting (at least 70 d) fading tail were recorded. The initial part of this outburst was not recorded due to the long observational gap. The supercycle of this object is estimated to be ~ 410 d.

2.5 ASASSN-20la

This object was detected at $g = 16.1$ on 2020 August 28. The light curve based on the ZTF, ASAS-SN, and ATLAS Forced Photometry data (figure 5) indicates the initial superoutburst lasting 6 d (JD 2459088–2459064) followed by a dip, and a possible second superoutburst (JD 2459098–2459101). Six post-superoutburst rebrightenings were detected on the fading tail. The shortness of the initial superoutburst is incompatible with a hydrogen-rich DN. The likely double superoutburst and the rapid fading rate (more than 2 mag d^{-1}) of rebrightenings also support the AM CVn-type classification. No previous outburst was detected in ASAS-SN (since 2013 November) and ZTF (since 2018 June). Even considering the seasonal observational gaps, the lack of previous signature of a fading tail suggests that the supercycle is longer than 900 d.

2.6 ASASSN-20lr

This object was detected at $g = 15.9$ on 2020 September 9. The light curve based on the ZTF and ASAS-SN data (figure 6) indicates the initial superoutburst lasting 5 d (JD 2459100–2459105). There were at least three post-superoutburst rebrightenings. As in ASASSN-20la, the short

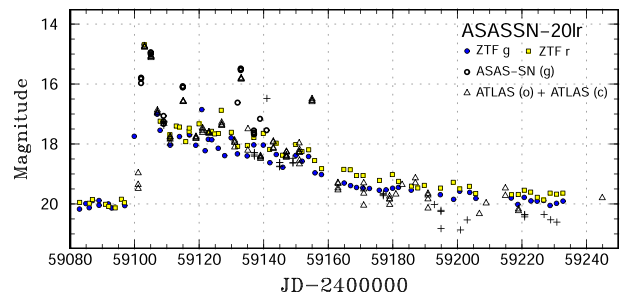


Fig. 6. Light curve of ASASSN-20lr. The filled squares and circles represent ZTF r and g observations, respectively. Open circles, triangles, and “+” signs represent ASAS-SN, ATLAS o , and ATLAS c observations, respectively. (Color online)

duration of the initial superoutburst and the rapid fading rate (more than 2 mag d^{-1}) of rebrightenings support the AM CVn-type classification. Pan-STARRS1 data recorded a fading tail in 2016 and the supercycle of this object is estimated to be ~ 7 yr.

3 Discussion

3.1 Number statistics

A total of six AM CVn candidates discovered within four months is amazingly high in number. They comprised 18% of 34 newly discovered ASAS-SN DN candidates during the same interval and had ZTF light curves with good temporal coverage and quality, allowing type classification. The total number of ASAS-SN DN candidates during the same interval was 111. The ratio of 18% appears to be too high to reflect the population statistics among DNe, and this high number may have simply been a result of random fluctuation. The estimated parent fraction of AM CVn candidates has a 95% confidence interval of [0.068, 0.345]. In fact, in our previous survey of SU UMa-type DNe (Kato et al. 2015a), we found that 8% of objects showing dwarf nova-type outbursts were AM CVn-type objects (eight out of 105 outbursts; all of them were confirmed either by spectroscopy or by the detection of superhumps or eclipses). The 95% confidence interval of the parent fraction of AM CVn stars in this sample was [0.033, 0.145]. This interval overlaps with the estimate in the present study. Combined with the sequence of recent discoveries of AM CVn stars or candidates [ASASSN-21au = ZTF20acyxwzf (Isogai et al. 2021), ASASSN-21eo (vsnet-alert 25635) and ASASSN-21hc (vsnet-alert 25849, 25868)] among ASAS-SN DN candidates, the recent statistics of outbursting objects may suggest a signature of a larger fraction of AM CVn stars among CVs than had previously been thought (e.g., about 1% in RKcat Edition 7.21; Ritter & Kolb 2003).

There may have also been selection biases, such as the past detection scheme in ASAS-SN could have detected

hydrogen-rich DNe more easily than helium ones (e.g., the short duration of superoutbursts in helium DNe would make detections more difficult in low-cadence surveys). Such a potential bias needs to be examined in more detail in discussing the fraction of AM CVn stars among DNe.

3.2 Post-superoutburst rebrightenings and fading tail

In hydrogen-rich CVs, multiple post-superoutburst rebrightenings are associated with WZ Sge-type DNe (Kato 2015), but not exclusively [e.g., V1006 Cyg, Kato et al. (2016); ASASSN-14ho, Kato (2020)]. Although the cause of these rebrightenings is still poorly understood, the infrared or red excess observed during the rebrightening phase or during the fading tail in hydrogen-rich systems (Uemura et al. 2008; Matsui et al. 2009; Chochol et al. 2012; Nakagawa et al. 2013; Golysheva & Shugarov 2014; Isogai et al. 2015b) is usually considered to arise from an optically thin region that is located outside the optically thick disk, and this matter in the outer disk would serve as a mass reservoir (Kato et al. 1998, 2004) to enable rebrightenings.

Among the AM CVn-type candidate we studied, ASASSN-20eq and ASASSN-20jt did not show significant red colors (ZTF $g - r$) during the rebrightening/fading tail phase (we refer to the colors in comparison with those around the outburst peak or in quiescence). This apparently is in clear contrast to hydrogen-rich systems. This may be a result of higher ionization temperature of helium compared to hydrogen, and optically thin region can still emit bluer light compared to hydrogen-rich systems. These instances suggest that the lack of red excess during the rebrightening/fading tail phase can be used for identifying AM CVn stars.

Two objects (ASASSN-20gx and ASASSN-20lr) showed a some degree of red color during the same phase. These instances suggest that the outer part of the disk can become cool enough to emit red light even in helium systems.

3.3 Implication on transient selection

As introduced in section 1, AM CVn stars have been receiving much attention in recent years. Selections of AM CVn stars from other CVs, however, have been a challenge in most cases. Since the fraction of AM CVn stars among CVs is low, there always arises a serious problem of detecting a small number of objects among the far numerous non-AM CVn background. This usually causes a large number of false positives (undesired hydrogen-rich systems) if the criterion is loose. With a more stringent

criterion, many false negatives (many AM CVn stars classified as ordinary CVs) occur. The small number of AM CVn samples would also provide a difficult condition in machine learning.

Using one of the criteria ($BP - RP < 0.6$) in van Roestel et al. (2021), ASASSN-20jt ($BP - RP = +0.76$) becomes a false negative among the three objects with known Gaia colors. Using their criterion of high priority candidates ($-0.6 < BP - RP < 0.3$) all three objects with Gaia colors in our sample are not considered as high priority. This indicates the limitation in choosing candidates by colors only (particularly in the presence of high number of “background” hydrogen-rich objects).

We propose to use the structure of the light curve as a better selection tool for AM CVn-type candidates. We also added some additional features useful for identifying AM CVn-type outbursts. They are:

- (1) Rapid fading (more than 1.5 mag d^{-1} during any part of the light curve).
- (2) Short duration (usually 5–6 d) of the superoutburst. In hydrogen-rich systems, superoutbursts usually last more than 10 d.
- (3) Double superoutburst. Double superoutbursts are rare in hydrogen-rich systems and the initial superoutburst of a double superoutburst lasts longer than 10 d (see, e.g., Kato et al. 2013). Rapid fading (item 1) after a ~ 5 d-long outburst (item 2) is a strong sign of an AM CVn system and observations that watch for the second superoutburst and emergence of superhumps are very desirable.
- (4) Long fading tail lasting 100–200 d despite the lack of long (usually more than 20 d in hydrogen-rich systems) superoutburst. The lack of red excess in this stage would also be a signature of an AM CVn system.
- (5) Outburst amplitudes of long outburst (4–6 mag) smaller than hydrogen-rich WZ Sge stars (6–8 mag or even more). This reflects the small disk size in AM CVn-type objects. Potential confusions with outbursts in hydrogen-rich systems with lower amplitudes (such as SU UMa stars or SS Cyg stars) could be avoided by confirming the absence of past outbursts.
- (6) In the same sense, a faint absolute magnitude (significantly fainter than +4) of a long outburst can be a signature of an AM CVn-type superoutburst, if the parallax is known. For example, the maximum absolute of ASASSN-20lr is $+6.3(4)$.

In summary, item 1 is probably the most useful in practice. If the number of observations is sufficient, item 2 is also very helpful. If the light curve is known long after the event, items 3 and 4 will be helpful. Items 5 and 6 will be

helpful if the quiescent counterpart can be identified or the Gaia parallax is available.

Incorporation of these features in automated recognizing system will certainly increase the success rate in follow-up spectroscopic observations.

Upon request by the referee Michael Coughlin, we provide (as Supplementary data online) a toy R code to implement the items 1 and 2. Using the actual ZTF r data, this code correctly recognized ASASSN-20eq, ASASSN-20jt, ASASSN-20ke (for the 2019 outburst), and ASASSN-20la as AM CVn-type superoutbursts while the data for the hydrogen-rich WZ Sge star AL Com did not pass this test. The reason why ASASSN-20gx did not pass the test was that there were observational gaps in the ZTF data, causing an apparent fading rate smaller than 1.5 mag d^{-1} (if we loosen the criterion to 1.2 mag d^{-1} , this object is recognized as an AM CVn star). The reason why ASASSN-20lr did not pass the test was the lack of observations immediately after the peak. The second observation by the ZTF was 4 d after the peak and it was impossible to measure the duration of the initial outburst only by the ZTF data. We hope others would benefit from this toy code and perhaps have ideas to turn it into a better filter.

Supplementary data

The following supplementary data is available at [PASJ](https://academic.oup.com/pasj/article/73/5/1375/6342195) online.

The toy R code (test.R) to detect AM CVn-type outbursts.

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