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The recurrent nova V3890 Sgr-a short review

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Recurrent novae eruptions are often observed in most if not all wavelengths from radio to gamma-rays. Here, we present some highlights from observations of the recurrent symbiotic nova V3890 Sagitarii that erupted again the third time in August 2019. Enough material accumulates on the surface of the white dwarf for a thermonuclear eruption to occur after every 29 years. The most recent eruption has been moderately studied over the whole electromagnetic range from GeV gamma-rays by the Fermi/LAT to 1 GHz radio observations with MeerKAT. Most of the different emission types observed from the nova are shock-powered. Observing emission of novae at different wavelengths is useful for determining the ejecta morphology of the nova, dust formation and studying the circumstellar environment around the binary system. High resolution images from the Karl G. Jansky Very Large Array show that the ejecta is not resolved more than a year post-eruption at 5 GHz. However, at 7 GHz, the ejecta show two blobs east-west direction with different brightness. We combine the radio image measurement with optical spectra measurements of velocities to estimate the distance to the nova.

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1. Introduction

Nova eruptions occur in Cataclysmic Variables (CV) as a result of thermonuclear runaway (TNR) which occurs on the outer layers of an accreting white dwarf (WD) [1, 2]. The WD accretes mass from either a main sequence, sub-giant, or red giant star [3]. Nova eruptions do not destroy the WD, consequently they are known to reoccur. The time between two eruptions can be from a few months to $\sim 10^5$ years [4, 5]. If a nova has more than one recorded eruption within a century, it is referred to as a recurrent nova. There are 10 known Galactic recurrent novae to date [6].

Recurrent novae (RNe) are broadly divided into two categories, long-orbital-period ($\sim$ 1 year) and short-period ($<$ 1 d) systems. There are four long-period systems, RS Oph, T CrB, V3890 Sgr, and V745 Sco which consists of an evolved red giant companion. Nova explosions violently expel 10^{-6} $M_\odot$ to 10^{-3} $M_\odot$ of the accreted material [5]. However, if the WD can grow in mass, despite mass loss after an eruption, then novae become viable channel for type Ia supernovae (SNe Ia) [7]. Since RNe consist of massive white dwarf and have short recurrence times, they are considered to be one of the pathways of thermonuclear supernovae. Some recurrent novae accrete material via Roche-Lobe overflow and stellar winds, hence could be used for accretion disc studies [8, 9]. The dense circumbinary environment around the binary system interact with ejected envelope to create a forward and reverse shock where regions of cool gas forms, making it possible for dust and carbon monoxide to form [e.g., 10].

Novae are normally discovered at optical wavelengths by amateur astronomers and are observed across all wavelengths up to gamma-rays. In this paper, we review multiwavelength observations from radio to gamma-rays of recurrent nova V3890 Sgr that recorded its third eruption in 2019 August. Previously known eruptions were recorded in 1962 June and 1990 April.

2. Optical observations

Novae are normally discovered at optical wavelengths as transients when the luminosity changes by 8 – 15 magnitudes, and in some cases, they can be seen with the naked eye over a few days. The optical peak of V3890 Sgr was recorded at $V \approx 7$ mag during the eruption from quiescence magnitude of 15 [11]. The optical peak was immediately followed by smooth decline similar to previous eruptions [12]. Optical light curves between 2010 and 2020, which include both quiescence and eruption phases were analysed to determine the orbital period of the binary system as 747.6 days [13]. V3890 Sgr, therefore fits in to the class of symbiotic recurrent novae with orbital periods of more than one year.

Spectroscopy studies of the nova with the Southern African Large Telescope (SALT), prior to eruption show that they are dominated by absorption lines from the matter originating from the red giant companion [13]. Post-eruption, the spectra obtained with various telescopes during the early phase of evolution (within days) are dominated by broad emission lines with velocities > 4000 km s^{-1} [14]. These velocities are similar in some symbiotic recurrent novae and are known to originate from expanding ejecta [15]. However, at later times post-eruption, the spectra show narrow emission lines superimposed on broad emission lines [16]. Both features become narrower as the eruption progresses to indicate deceleration of the ejecta as it collides with pre-existing wind which is common among these systems [16, 17].

3. Shock-powered emission

The WD in V3890 Sgr accretes material through Roche Lobe overflow or winds resulting in a dense surrounding medium [8]. As a result of the TNR, the outer layers of the WD are expelled and interacts with pre-existing dense winds. Consequently, regions of shocked emissions are produced. Observational signatures of these shocks are observed at different wavelengths, as discussed below.

3.1 Radio observations

Novae ejecta emit both thermal and non-thermal emission as observed in radio light curves and high resolution radio imaging [18, 19]. The evolution of nova radio light curves takes months to years and brighten as the radio emitting region expands. Synchrotron emission observed in V3890 Sgr is similar to that observed in other recurrent novae such as RS Oph [20] and V745 Sco [21]. The multifrequency high cadence radio light curves of V3890 Sgr obtained with the Karl G. Jansky Very Large Array (VLA) and MeerKAT are presented in Nyamai et al. [12]. The evolution of the radio spectral index over time is consistent with non-thermal emission from accelerated particles. The non-thermal radio emission which originates from the nova ejecta interacting with the dense circumbinary material is modelled to estimate the the mass loss rate from the companion star [12]. This model assumed a spherical nova ejecta interacting with uniformly distributed surrounding medium. However, as we see below in the high resolution images, the ejecta geometry is not simplistic and this should be taken into account when estimating the mass-loss rates.

Figure 1 shows high resolution images of V3890 Sgr at 6 cm observing wavelength following the most recent eruption. If nova ejecta are resolved at early times, the images provide information on mass ejection processes and evolution of shocks with time. The VLA image on day 535.7 after eruption at 5 GHz shows an almost circular emission while that at 7 GHz show two lobes with the western side significantly brighter. The day of eruption is taken as 2019 August 27.9 UT (MJD = 58722.9) and the images were obtained on 2021 February 13.6 UT (MJD = 59258.6).

For an expanding nova shell, the distance to the nova can be estimated by combining estimated shell sizes from resolved nova ejecta and velocities of the expanding material. The centers of the east and west components in the 7 GHz VLA image are separated by $\approx$ 0.44 arcsecs. Assuming that V3890 Sgr is at a distance of 9 kpc [13], we determine the possible ejecta velocity required to reach this separation after 535.7 days of expansion. Assuming that the ejecta was expanding at constant velocity, we obtain a velocity value of 6400 km s^{-1}. However, on day 1.2 after nova eruption, Strader et al. [14], determined a maximum initial expansion velocity of $\approx$ 4200 km s^{-1} using emission lines at optical wavelengths. If this initial velocity represents the velocity for the radio emitting material throughout the evolution of the ejecta, we estimate a distance of $\sim$ 5.9 kpc. We can assume this velocity value for the ejecta since the full width at half-maximum values of broad components for hydrogen and helium lines in infrared spectra remained constant for days after eruption [16]. However, estimating the distance from a single image is very uncertain and needs to be verified with other observations or independent methods or analysis of more radio images.

The VLA images for V3890 Sgr are not different from high resolution images of other individual symbiotic systems, which have been done using the VLA, the European Very Long Baseline Interferometry (VLBI) Network (EVN), the Very Long Baseline Array (VLBA) and the Multi-Element Radio Linked Interferometer Network (MERLIN) [22, 23]. These telescopes offers high

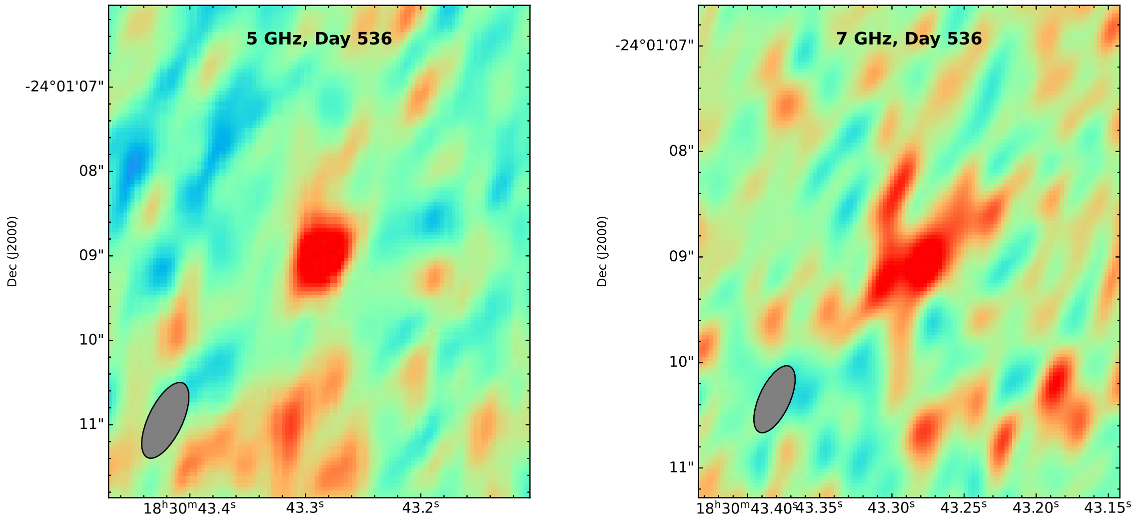

Figure 1: (Left) VLA A configuration images of V3890 Sgr obtained on 2021 Feb 13.6 (MJD 59258.6, 535.7 days after eruption) at 5 GHz. (Right) VLA A configuration images of V3890 Sgr obtained on the same day at 7 GHz. The gray ovals represent the synthesized beam.

sensitivity and resolution that is able to resolve the nova ejecta as it is shaped by the surrounding medium soon after eruption. The images show expanding nova ejecta morphologies which are possibly shaped by the red giant wind or mass ejection processes [24, 25]. There are no published X-ray, *Hubble Space Telescope* (HST) and Center for High Angular Resolution Astronomy (CHARA) array images for V3890 Sgr yet. High-resolution spectroscopic observations show multi-component profiles of emission lines implying bipolar outflows consistent with the radio images [16].

3.2 X-ray observations

V3890 Sgr was observed with several X-ray instruments and recorded to produce hard X-rays and soft X-rays days following the eruption [26–29]. Hard X-rays originate from the same region as non-thermal emission in the radio and gamma emission. *Swift* and AstroSat observations reveal hot X-ray emission from heated gas days after eruption [27, 28]. V3890 Sgr was observed as a supersoft source (SSS) within days following eruption [27]. Soft X-rays are produced at nebular phase of the nova before it fades to quiescence levels. During this time the ejecta is optically thin and the residual burning on the surface of the compact object becomes a source of soft X-rays observed in the supersoft X-ray phase.

3.3 Gamma-ray observations

V3890 Sgr was detected in gamma-rays soon ($\sim$ 2 days) post-eruption [30]. The evolved secondary star in a recurrent nova system expels a dense wind. This wind interacts with the nova ejecta, which is expanding at several thousand kilometers per second, creating an external shocked region where high-energy radiation such as synchrotron emission is produced. However, recent analysis of optical spectra from similar recurrent nova RS Oph show different velocities from Balmer emission line components. The velocities show correlation with optical and gamma-ray light curves and thus, Diesing et al. [31] used the different velocities to model a multiple shock model to explain the GeV and TeV emission in RS Oph. Diesing et al. [31] concluded that the origin of the emission is likely internal shocks within the ejecta. It is not clear if the internal shocks are homogeneous to other recurrent novae. Detailed analysis of gamma-ray emission from V3890 Sgr should be done to establish if the emission originates from internal shocks within the ejecta or external shocks of nova blastwave. The physical origin of gamma emission is likely acceleration of both protons and electrons.

4. Conclusion

Multiwavelength observations of symbiotic recurrent nova V3890 Sgr following the 2019 eruption revealed effects related to an efficient particle acceleration at the shocked regions external to the binary system. The direct radio images of the expanding nova ejecta provide information that the blastwave from the explosion is not symmetric. This is consistent with ejecta morphology deduced from near infrared specrtra. Using expansion parallax method, we utilise the VLA images to estimate a distance of $\sim$ 5.9 kpc to the nova. This value is within the range of other estimates of the distance using different methods including *Gaia* DR2.

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