AT2020caa: A Type Ia Supernova with a Prior Outburst or a Statistical Fluke?

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ABSTRACT

We recently discovered an extragalactic transient, AT2020caa, using the community alert broker ANTARES. This transient apparently exhibited two outbursts in a time span of a year (between 2020 and 2021). Based on a decade-long historical light curve of the candidate host galaxy, we rule out an activity from the galaxy nucleus to explain these outbursts. The measured peak magnitudes (assuming the known spectroscopic redshift of the candidate host galaxy) put AT2020caa in the realm of thermonuclear supernovae (SNe) or luminous core-collapse SNe. A handful of the latter are known to show prior outbursts (POs), thought to be linked to mass loss in massive stars. Using Gemini/GMOS, we obtained a spectrum of the current outburst that shows it to be a Type Ia supernova (SNIa). We examine the nature of AT2020caa’s PO and conclude that it is likely a separate SN within the same galaxy.

Modern wide-field, high-cadence optical surveys, such as the ongoing Zwicky Transient Facility (ZTF; Bellm et al. 2019), regularly deliver thousands of supernovae (SNe) – thermonuclear as well as core-collapse events – per year. We discovered the transient event ZTF20aamibse1 (AT2020caa, hereafter 20caa) from the real-time alert stream of ZTF using the community alert-broker ANTARES (Matheson et al. 2021). It is located at (J2000) RA 14h19m18.61s, Dec +00d03m27.86s, 1′′58 offset from the bright nucleus of a candidate host galaxy SDSS J141918.50+000327.8 (hereafter, SDSSJ1419) at a spectroscopic redshift of 0.097 (Ahn et al. 2012; see Fig. 1 Panel a) and a distance of around 460 Mpc ($H_0 = 67.8, \Omega_M = 0.307$; Planck Collaboration et al. 2014). In addition to the offset of 20caa from the nucleus, the decade-long light curve of this galaxy from the Catalina Sky Survey (Drake et al. 2009) does not show any variability, thus ruling out activity from an active galactic nucleus.

The ZTF light curve of 20caa based on forced photometry is shown in Fig. 1 (Panel b). It reveals a current outburst with an observed peak absolute magnitude $M_r = −19.4$ mag on MJD 59252 (2021 February 7 UT). This peak brightness puts 20caa in the realm of supernovae. Interestingly, it also showed a prior outburst (PO, hereafter) about a year before, just a few tenths of a mag fainter than the current outburst. The PO lasted (i.e., was above the detection threshold) for around a month. Note that this PO was also observed by the ATLAS survey (Tonry et al. 2018)2. Pre-explosion outbursts have been observed in a handful of core-collapse SNe (e.g., Mauerhan et al. 2013). Their underlying mechanism is, however, not yet understood and is likely to be closely linked to ill-constrained processes in massive-star evolution such as mass-loss. Nevertheless, such POs are faint, typically peaking at $>−15$ mag (e.g., SN2010mc; Ofek et al. 2013).

We obtained a spectrum for the 2021 event on 19 February (UT) with GMOS on Gemini South under a director’s discretionary program (GS-2021A-DD-102; PI: Soraisam). The spectral signature is consistent with a Type Ia supernova (SNIa) at a phase of around 14 days past maximum, and a redshift of 0.095 ± 0.005 (based on SNID, Blondin & Tonry 2007), which agrees with that from the narrow emission lines in the spectrum and is consistent with the redshift

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1 https://antares.noirlab.edu/loci/ANT2020l2ixy

2 Based on the ATLAS forced photometry service, the measurement reported by the survey to TNS appears overestimated (possibly due to contamination by the host galaxy given the large pixel scale of 1.86 for ATLAS).
Figure 1. Panel (a): Color (g,r,z) cutout from the DESI Legacy Imaging Survey (Dey et al. 2019) showing the location of 20caa (green circle) with respect to the bright nucleus of the galaxy SDSSJ1419 (magenta +). Another galaxy, MGC 60395, can also be seen north of the former. Panel (b): Light curve of 20caa based on forced-photometry of difference images from the ZTF survey. Triangles denote 5σ upper limit while the dotted line marks the epoch when the spectrum was obtained for the 2021 event. Note the break in the horizontal axis; this is done to highlight the two outbursts. Panel (c): Spectrum of 20caa obtained with Gemini-S GMOS, along with the best-fit SNIa spectrum (SN1990N; Phillips et al. 1992).
of SDSSJ1419. We also triggered target-of-opportunity observations with \textit{Swift}. In line with the SN Ia interpretation, we did not detect the event in X-rays from two epochs of \textit{Swift} observations on February 20 and 25 (UT).

**NATURE OF THE DOUBLE EVENT**

We explore three scenarios for the nature of the 2020 event of 20caa in light of the evidence we gathered for the current 2021 explosion.

**LENSED SN?**

There is another galaxy near 20caa, MGC 60395 at a redshift of 0.0974 (Liske et al. 2015), marginally larger than that of SDSSJ1419. The redshift of 20caa determined from its spectrum allows both SDSSJ1419 and MGC 60395 to be its host. Given that it is not possible to get effective lensing between two galaxies that are relatively close to one another as compared to their distances from the observer (cf. Wambsganss 1998), we rule out lensing for 20caa.

**PRIOR OUTBURST?**

The nature of SNIa progenitors is one of the biggest open questions in astronomy. Among the candidate progenitors, the single-degenerate scenario with an accreting white dwarf that produces recurrent novae is perhaps the only one that can be associated with historical outbursts of significant strength. Yet, the peak absolute magnitudes of novae reach just around -11 mag (see Fig. B.1 in Soraiaim & Gilfanov 2015), too dim to account for the PO.

**SN SIBLINGS?**

Multiple cases of sibling SNe, i.e., those sharing the same host galaxy, have been observed in the past (e.g., Anderson & Soto 2013; Scolnic et al. 2020). This is not surprising, given the typical overall SN rate of one per galaxy per century. However, for all of the ones with discernible extended host galaxies, the siblings are spatially well-separated. Note that a recent SN sibling from the DES survey, DES16C3nd0 and DES16C3nd1 (Scolnic et al. 2020), occurred within 1″ and temporally separated by 200 days. Nevertheless, at a relatively large redshift of 0.65, the angular extent of their host galaxy is comparable to 1″, which reconciles the spatial coincidence of DES16C3nd0 and DES16C3nd1.

Assuming the 2020 event of 20caa is a sibling SN, both of which occurred in the galaxy SDSSJ1419, we assess the likelihood of their spatial coincidence. The peak absolute magnitude $M_r$ of the 2020 event from ZTF is then $-19.04$ (corrected for Galactic extinction; Schlafly & Finkbeiner 2011). This peak brightness points to it being a SN Ia (though some core-collapse, interacting SNe, SN1998s-like, were also found to reach such a brightness).

For ZTF observations, the typical FWHM of the image PSF is 2″, with a pixel scale of 1″/01 (Bellm et al. 2019). The ANTARES broker conservatively uses a radius (ANT$_\text{res}$) of 1″ to aggregate alerts into a single locus, with the position of this locus assigned to the centroid of the group. For 20caa, there appears an offset of 1″3 between the 2020 and 2021 events. This offset may be instrumental in nature, given the presence of the nearby bright nucleus that can influence difference imaging, or it may indeed be real. For the latter case, we determine below the probability of seeing a double SN in a galaxy with the two explosions occurring in such close angular proximity of each other.

SDSSJ1419 is typed as a spiral Sab galaxy (e.g., Huertas-Company et al. 2011). We use the SNIa rate-size relation for galaxies of Sab morphology from Li et al. (2011) and the stellar mass of SDSSJ1419, log($M/M_\odot$) = 10.38 from Brinchmann et al. (2004), to compute its SNIa rate, which we obtain as $0.42_{-0.07}^{+0.07}$ per century. To be conservative, we also consider rates of core-collapse SNe on Li et al. (2011) $-0.38_{-0.08}^{+0.12}$ and $0.46_{-0.07}^{+0.08}$ per century for SNeIbc and SNeII, respectively — and obtain a total SN rate of roughly 1.26 per century.

Using the average Kron radius of SDSSJ1419 from PS1 DR2 (Chambers et al. 2016) to estimate the area of the whole galaxy and its total SN rate from above, we obtain the rate of SNe within a circular region of radius 1″ (ANT$_\text{res}$) as $1.8 \times 10^{-4}$ yr$^{-1}$. For a given SN in this region, the probability of observing a second SN within a year by ZTF, $p(\Delta t < 1$ yr) = $1.2 \times 10^{-4}$. Note that for the 3 day cadence of the public ZTF survey, its completeness for SN detection is largely determined by the visibility of the given galaxy, which we have factored into our computation. However, 20ca was selected from the output of a filtered stream (active since half a year ago) on ANTARES and therefore we need to account for the ‘look-elsewhere effect.’ To this end, we compute a similar probability $p_i(\Delta t < 1$ yr) for each of the roughly $N = 1000$ sources in this stream with SN-like light curve and discernible host-galaxy, assuming a typical SN rate of 1.5 per century for each galaxy. We then obtain the probability $(1 - \prod_{i=1}^N (1 - p_i(\Delta t < 1$ yr))) of seeing a double event for one or more of the events in our filtered stream as 27%.

In the absence of other possibilities (as discussed above), and given this appreciable probability for a chance encounter with such SN siblings, we consider the 2020 and 2021 events of 20caa as SN siblings. In this case, the spatial and
temporal proximity of the siblings coupled with the fact that SDSSJ1419 is a star forming galaxy (log SFR (M⊙ yr⁻¹) = 0.6; Brinchmann et al. 2004) provide an opportunity to investigate their influence on the host galaxy local environment. Additionally, the 2020 SN appears likely an SNIa, in which case 20caa will be an addition to the growing sample of SNIa siblings that can be used to investigate the influence of host galaxy properties on SNIa-based distances. The fact that we could detect such spatially and temporally close SN siblings despite their rarity and having used the particular ANTARES alert stream that flagged it for only about half a year points to the power of large-scale time-domain surveys like ZTF when coupled with ANTARES’ automated alert-filtering capabilities.

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