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Supernovæ

Workshop 8

M. Stritzinger[1] **and T. J. Moriya**[2]†

[1]Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark
email: max@phys.au.dk

[2]NAOJ, National Institutes of Natural Sciences, Mitaka, Tokyo, Japan

Abstract. This Workshop covered a cornucopia of topics that were featured in short formal presentations, followed by a round-table discussion. G. Hosseinzadeh and H. Kuncarayakti presented the results of their recent researches into interacting supernovæ. They included both the intriguing Type Ibn supernova subclass, and SN 2017dio, which appears to be the first Type Ic supernova to be seen to exhibit signatures of hydrogen-rich circumstellar interaction at all phases. M. Sullivan provided a summary relating to the future of transient science in the era of Big Data, and participants discussed strategies to determine which targets and fields should be selected for spectroscopic follow-up. The Workshop concluded with a rather heated discussion regarding the need for the IAU Supernovæ Working Group to consider modifying the current criterion for a confirmed supernova in order for it to receive an official IAU designation.

Keywords. Supernovæ, transient surveys, IAU transient naming criterion

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1. Introduction

This report summarises the principal discussions that took place during the Supernovæ Workshop. The topics that were formally chosen were planned to highlight new scientific results with the intention of inspiring discussion on a number of aspects related to the transient Universe. The format we selected consisted of a few short presentations that served as launch points to stimulate round-table discussion. The first part of the Workshop focused on stripped-envelope supernovæ that exhibit signatures of circumstellar interaction, while the second part focused on future surveys, and on IAU transient classification criteria.

After the organizers gave a quick briefing of the Workshop format, G. Hosseinzadeh opened the first session with a review of the observational properties of today's sample of Type Ibn supernovæ. It was followed by H. Kuncarayakti's presentation on the recently studied Type Ic supernova (SN) 2017dio, which exhibits clear signatures of hydrogen-rich circumstellar interaction at all phases of its evolution. The second session, which was mainly a discussion of the status of transient surveys, was initiated by M. Sullivan's review of past, current and future transient search programmes. S. Mattila then presented several examples of highly extinguished transients that are clearly supernovæ yet the current IAU criteria does not allow them to receive a bonafide IAU supernova designation. This matter led to a rather heated debate among the workshop participants; there appeared to be a general consensus that the IAU Supernovæ Working Group should address this untenable situation in the immediate future.

† Fellow of the National Astronomical Observatory of Japan

2. New Types of Interacting Supernovæ

2.1. *Type Ibn supernovæ (presented by Griffin Hosseinzadeh)*

Type Ibn supernovæ are supernovæ interacting with helium-rich circumstellar media. Their spectra are dominated by narrow helium emission lines (FWHM ~ 2000 km s^{-1}) with little or no hydrogen. After the first identification of Type Ibn (SN 1999cq; Matheson *et al.* 2000), many studies of individual objects, including SN 2006jc with a pre-burst (Pastorello *et al.* 2007), have been performed. Hosseinzadeh *et al.* (2017) recently reported the observations of six new objects, and those results were presented. To the best of our knowledge, as of the time of writing the sample of Type Ibn supernovæ reported in the literature numbers about 22 objects.

Light-curves of Type Ibn supernovæ are much more homogeneous than those of Type IIn supernovæ that interact with hydrogen-rich circumstellar media. They rise to peak in less than 10 days and decline at a rate of ~ 0.1 mag day^{-1}. Their decline is also much faster than that of Type IIn supernovae. Analysing their fast evolving light-curve, Moriya & Maeda (2016) suggested that the circumstellar media in Type Ibn supernovæ are likely to be confined near the progenitors. However, it is curious that the narrow spectral features driven by the interaction appear for weeks or even months following the explosion.

Early spectra of Type Ibn supernovæ can be classified broadly into two types. One sort typically exhibits narrow P-Cygni helium profiles superposed on a blue continuum, while the other type shows narrow helium emission without P-Cygni absorptions, on top of broader features. The spectra of both types evolve and appear similar within $\sim$1 month after the explosion. The narrow P-Cygni profiles may result from optically thick circumstellar material, while Type Ibn supernovæ with or without weak P-Cygni profiles may only have optically thin circumstellar material. However, there can exist observational biases, i.e., all Type Ibn supernovæ may show narrow P-Cygni lines if observed early enough after the explosion. If the circumstellar material is aspherical, viewing angles could also play an important role in shaping the characteristics that are observed.

All known Type Ibn supernovæ appear in star-forming galaxies, except for PS1-12sk (Sanders *et al.* 2013). The *Hubble Space Telescope* is scheduled to observe the location of PS1-12sk in the near future, in order to search for star-formation activities around the location of this supernova.

Light-curve properties of Type Ibn supernovæ are very similar to those of rapidly-evolving luminous transients reported by Drout *et al.* (2014). Indeed, some Type Ibn supernovæ show blue continua within a week from peak brightness, while others in the sample might have experienced interaction with helium-rich circumstellar shells without showing clear helium signatures. The fraction of Type Ibn supernovæ is estimated to be only a few percent of the total core-collapse supernovæ rate. If Drout's objects also have helium-rich circumstellar media, almost 10% of core-collapse supernovæ could experience interaction with a dense, helium-rich circumstellar media.

2.2. *A Type Ic supernova interacting with a hydrogen-rich circumstellar medium (presented by Hanin Kuncarayakti)*

This segment of the first session provided the participants with observations of an object that appears to be unique among supernovæ. SN 2017dio was discovered by the ATLAS survey on 16 April 2017 (UTC) in a faint galaxy at a redshift of $z = 0.037$. Upon ignoring narrow emission lines in the spectrum, it was classified as a Type Ic supernova (Cartier *et al.* 2017). However, narrow hydrogen and helium emission lines are clearly present in its spectra, which has – up to now – never been seen in a Type Ic supernova at early phases.

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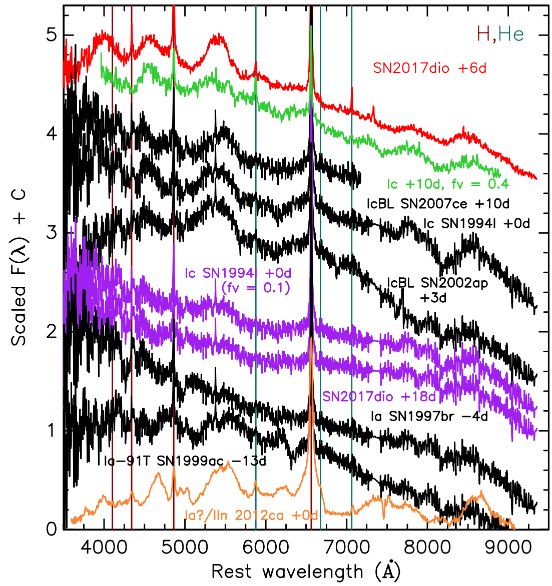

Figure 1. A spectrum of SN 2017dio compared to those of several types of supernovæ coadded with CSM interaction component: see Kuncarayakti *et al.* (2018).

Three spectra observed within 6 days after the discovery are found to be very similar. Then, the spectrum takes on a rather blue and featureless continuum, similar to that of Type IIn supernovæ. The late-phase spectra are also found to resemble the spectra of Type IIn supernovæ. Narrow (FWHM ~ 500 km s^{-1}) hydrogen and helium emission lines are always present in the spectra of SN 2017dio, suggesting the existence of a dense circumstellar medium. The early spectra are similar to those of Type Ia supernovæ with circumstellar interaction (e.g., SN 2002ic), but the underlying spectra (without the narrow lines) match those of broad-line Type Ic supernovæ (see Fig. 1).

The light-curve of SN 2017dio has distinct features with two peaks. The light-curve towards the first peak is well fitted by a Type Ic supernova template of Taddia *et al.* (2015) with an absolute peak g-band magnitude of -17.5. Then, the luminosity starts to increase again for more than 50 days and reaches a second peak with an absolute g-band magnitude of -18.8. The peak magnitude of the second maximum suggests that there is no Type Ia supernova hidden below because at optical wavelengths they reach maximum brightest during their first peak, and the first peak of SN 2017dio is too faint for a Type Ia supernova. Close inspection of the spectra suggests SN 2017dio is probably a Type Ic supernova, with at least $30-40\%$ of its luminosity contribution produced from circumstellar interaction (e.g., Leloudas *et al.* 2015). Kuncarayakti *et al.* (2018) argue that the origin of the circumstellar medium surrounding SN 2017dio is related to significant mass loss ($\sim 10^{-2}$ M$_\odot$ yr^{-1}) from the progenitor system which occurred in the decades preceding its final demise. The asymmetric spectral lines suggest the circumstellar medium is asymmetric. The big question is then: how does a hydrogen- and helium-free supernova progenitor obtained a hydrogen-rich circumstellar medium? To find a possible solution we turn to binary evolution to answer this question. A possible binary model consists of a primary star that evolves to be a carbon and oxygen star after Roche-lobe overflow. Meanwhile, its secondary companion evolves to a luminous blue variable, or a giant, driving a second phase of Roche-lobe overflow. The primary star explodes at this moment with a hydrogen-rich circumstellar medium created by the secondary star.

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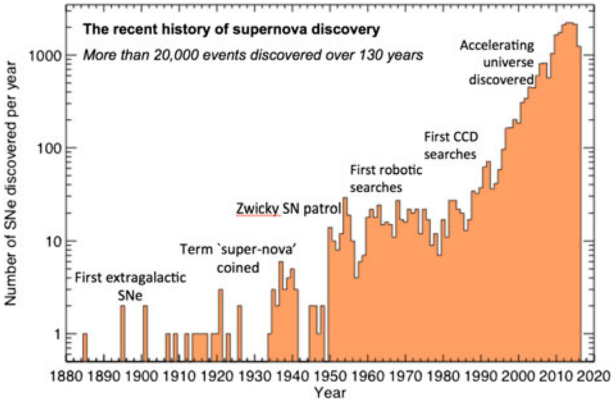

Figure 2. Histogram of supernovæ discoveries since the 1880s. Updated from Sullivan (2013).

There are objects that are probably related to SN 2017dio. Type Ibn supernovæ previously mentioned are obvious. In addition, SN 2014C (Milisavljevic *et al.* 2015) and SN 2001em (Chugai & Chevalier 2006) are Type Ib and Type Ic supernovae, respectively, that exhibited narrow hydrogen features approximately one year after their explosions, and the existence of detached hydrogen-rich circumstellar media around hydrogen-free supernova progenitors has been suggested. SN 2010mb is another Type Ic supernova with circumstellar interaction, but it did not show any hydrogen and helium features (Ben-Ami *et al.* 2014). Some superluminous Type Ic supernovæ are known to have late-phase hydrogen emission that begins to appear after a year from the light-curve peak (Yan *et al.* 2017). A few other Type Ib/Ic supernovæ have been suggested to exhibit late-phase hydrogen emission lines (Vinko *et al.* 2017), but SN 2017dio is the *first* Type Ic supernova that shows signatures of hydrogen-rich circumstellar interaction right from the beginning.

An interesting question to consider is how many Type IIn supernovæ without early spectra are like SN 2017dio. The late-phase spectra of SN 2017dio are similar to Type IIn supernovæ and it might have been classified as Type IIn supernovæ had the early spectra not been obtained. Other 2017dio-like objects might previously have been misclassified as Type IIn supernovæ.

3. Surveys and IAU SN Designation

3.1. *History, present and future of transient surveys (presented by Mark Sullivan)*

Over the past 130 years (see Fig. 2), time has witnessed the discovery of the first extragalactic supernova (at the end of the 19$^{\text{th}}$ Century), the coining of the term 'supernova' in the 1930s (Baade & Zwicky 1934), the emergence of the first robotic searches in the 1960s, and then the development, implementation and deployment of CCD cameras in the 1980s. By the late 1990s, with the combination of experience and the advent of larger and more efficient CCDs, observations of Type Ia supernovæ led to the startling discovery that the expansion rate of the Universe is accelerating. During the modern era 20,000 supernovæ have been discovered, and between the start of the Calán/Tololo survey and the current Dark Energy Survey on average about 5 supernovæ have been discovered and confirmed each day.

Combined efforts of countless astronomers have revealed the existence of a multitude of transient objects associated with the terminal demise of their progenitor star(s). Today, researchers in the field study a range of supernova types, extending from the very bright to the very faint; however, our knowledge of the transient Universe on short time-scales remains largely unexplored territory. The hope is that this will change in the future with on-going and new high-cadence searches, e.g., ATALS, ASAS-SN, BlackGem, ZTF and LSST.

Transient science is also in the midst of a sea change, as the near future marks the era of Big Data. For example, LSST is expected to produce 100,000 transient alerts per night, based on 20 Terabytes of data. Integrating over its planned 5-year lifetime, LSST is expected to produce some 10 million supernovæ discoveries! How to manage the study of all those objects presents a significant challenge, and solid selection criteria must be developed in order to determine which objects to study. This problem will be exacerbated by a shortage of adequate spectroscopic follow-up facilities. Sullivan's presentation argued forcefully that constructing a sample of $\sim$ 30,000 supernovæ with spectroscopic confirmation is well within grasp of the European Southern Observatory's new VISTA telescope and 4MOST survey, which will build on experience gained by the AAT/OzDES survey.

3.2. *The IAU SN designation criterion (presented by Seppo Mattila)*

As of 2016 January 1, the Transient Name Server was adopted as the official IAU instrument for reporting astronomical transient candidates. At present, a transient can only obtain an IAU supernova designation (e.g., SN 2018xx) once it is given a spectroscopic type. That criterion is a continuation of the scheme previously adopted by the Central Bureau for Astronomical Telegrams, and is rooted in a time when there was effectively no means of finding highly extinguished supernovæ in searches limited to optical wavelengths.

Today's technology has transformed the way in which some of us search for supernovæ, and as a result the current naming criterion is not always adequate. As pointed out by Mattila, over the past several years the SUNBIRD collaboration, which makes use of laser guide-star adaptive optics in the near-IR, has discovered a number of core-collapse supernovæ in luminous infrared galaxies (e.g., Kool *et al.* 2018). However, owing to high extinction in galactic nuclear regions it is often not possible to obtain clear optical detections, let alone a visual-wavelength spectrum in order to secure an IAU supernova designation. Furthermore, near-IR spectroscopy is often equally challenging for faint supernovæ that are seen against the bright and crowded nuclear regions of luminous infrared galaxies.

Near-IR and/or radio follow-ups can confirm the supernova nature of such events without any doubt, even in the absence of spectroscopic confirmations. As an example of such an object, Mattila pointed out the case of SN 2008iz (among others), which occurred in the very near starburst galaxy M82 and was discovered at radio wavelengths (Brunthaler *et al.* 2009). Although this object had no detected optical emission, adaptive optics K-band imaging obtained with Gemini-N provided a detection at a much later date after the event (Mattila *et al.* 2013). The VLA provided radio light-curves consistent with a core-collapse supernova, and VLBI radio imaging revealed an expanding shell, confirming without any doubt that SN 2008iz is a core-collapse supernova (see Kimani *et al.* 2016).

After some heated debate on this subject there appeared to be a general consensus that the IAU Supernovæ Working Group should be asked to consider modifying the current IAU criterion for official supernova name designation. In doing so, the IAU can ensure that all supernovæ discovered within our own Galactic neighbourhood are able to be given the IAU designation that they rightfully deserve.

References

Baade, W., & Zwicky, F. 1934, *Proc. Natl. Academy of Sciences*, 20, p. 254
Ben-Ami, S., Gal-Yam, A., Mazzali, P. A., *et al.* 2014, *ApJ*, 785, 37
Brunthaler, A., Menten, K. M., Reid, M. J., *et al.* 2009, *A&A*, 499, L17
Cartier, R., Gutierrez, C. P., Smith, M., *et al.* 2017, *ATel*, 10334
Chugai, N. N., & Chevalier, R. A. 2006, *ApJ*, 641, 1051
Drout, M. R., Chornock, R., Soderberg, A. M., *et al.* 2014, *ApJ*, 794, 23
Hosseinzadeh, G., Arcavi, I., Valenti, S., *et al.* 2017, *ApJ*, 836, 158
Kimani, N., Sendlinger, K., Brunthaler, A., *et al.* 2016, *A&A*, 593, 18
Kool, E. C., Ryder, S., Kankare, E., *et al.* 2018, *MNRAS*, 473, 5641
Kuncarayakti, H., Maeda, K., Ashall, C. J., *et al.* 2018, *ApJ*, 854, 14L
Leloudas, G., Hsiao, E. Y., Johansson, J., *et al.* 2015, *A&A*, 574, 61
Matheson, T., Filippenko, A. V., Chornock, R., *et al.* 2000, *AJ*, 119, 2303
Mattila, S., Fraser, M., Smartt, S. J., *et al.* 2013, *MNRAS*, 431, 2050
Milisavljevic, D., Margutti, R., Kamble, A., *et al.* 2015, *ApJ*, 815, 120
Moriya, T.J., & Maeda, K. 2016, *ApJ*, 824, 100
Sanders, N. E., Soderberg, A. M., Foley, R. J., *et al.* 2013, *ApJ*, 769, 39
Sullivan, M. 2013, *Astron. Geophys.*, 54, 17
Taddia, F., Sollerman, J., Leloudas, G., *et al.* 2015, *A&A*, 574, 60
Pastorello, A., Smartt, S. J., Mattila, S., *et al.* 2007, *Nature*, 447, 829
Vinko, J., Pooley, D., Silverman, J.M., *et al.* 2013, *ApJ*, 837, 62
Yan, L., Lunnan, R., Perley, D.A., *et al.* 2017, *ApJ*, 848, 6