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Historical Novæ and Supernovæ

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Abstract. This paper brings together the chief points raised during FM5 by astronomers, archaeologists, and historians whose research interests centred on novæ and supernovæ. The common focus was the use of historical observations to study transient astronomical phenomena. The presenters covered a wide variety of topics within that theme, and this report summarizes some of the aspects specific to historical novæ and supernovæ.

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1. Fundamental Properties of Novæ and Supernovæ

Novæ and supernovæ are extreme, and usually unpredictable, brightenings of stars. They have been observed since at least two millennia ago, recorded by Chinese astronomers as "guest stars" (Clark & Stephenson 1982). A nova occurs when a white dwarf in a binary system accretes enough hydrogen onto its surface to trigger a runaway thermonuclear reaction, causing an eruption in the surface layer. Supernovæ come in two basic types: thermonuclear, or Type Ia (when either one white dwarf reaches the Chandrasekhar mass limit and explodes (single-degenerate) or when two white dwarfs in a binary (double-degenerate) merge and thereby exceed the Chandrasekhar mass limit), and core collapse (when a massive star runs out of fuel in its core and can no longer sustain fusion, causing a rapid collapse and explosion). Supernovæ and neutron star mergers produce and distribute the elements from CNO up to Th, U, and Pu; they heat and stir interstellar gas and dust, push gas and dust out of galaxies, trigger the formation of new stars, accelerate cosmic rays, and produce pulsars, X-ray binaries, neutrinos and (probably) gravitational waves. They aid the mapping of dark matter in galaxy clusters, measuring cosmological distances, and feeding magnetic fields into galaxies. Their records appear in many formats, from ancient written records to possible variations in ionic concentrations in geological records to (more recent) glass plates. The talks and posters presented on this theme reflected that variety.

Both novæ and supernovæ can simulate the appearance of temporary new stars, and can be bright enough to be seen with the naked eye from days to months, depending on the distance and type of event. Additionally, instabilities in the disks surrounding accreting white dwarfs can produce small outbursts known as dwarf novæ, which are not bright enough to appear in historical records but which can now be observed in systems that were previously identified by ancient astronomers as guest stars.

1.1. *Historical supernovæ as research tools*

Despite the danger of small number statistics, historical supernovæ (of which there are some 7–14) can tell us something about SN rates, types, parent populations, 3-D structures, what they put into the ISM, their formation, initial rotation and magnetic fields, and early evolution of neutron stars and black holes, late mass loss from massive stars, nucleosynthesis, and more. For some systems, such as CM Tau (also known as the Crab Pulsar, SN 1054, NGC 1952, 3C144, Tau X-1, NP0532) the observational evidence is still evolving, as publications find different mass values, detect a pulsar (with rather slow initial rotation), a jet off to one side, and a gamma ray source. The full ensemble includes 1572 (Tycho), 1604 (Kepler), Cas A, SN 1006, the progenitor of SNR 0519-76.5, S And, RCW86 = SN 185, and 1987A in addition to SN 1054. The statistics suggest that we are overdue for another Galactic event, and that classification can be difficult.

1.2. *Novæ and supernovæ in ancient records*

Pre-telescope ("historical") supernovæ events in the Milky Way were recorded by sky watchers of several different cultures (though not by all that could have done so). The ancient Egyptians expected new stars when the souls of pharaohs rose to the heavens (Trimble 1964), but we find no inscriptions or papyri confirming such events. The Babylonian tradition, as preserved in *Genesis*, puts all star births on the fourth day of creation, so no new ones are expected. Mayan records include astronomically-based calendars, but no supernova-like items (but it is important to note that many records were burned in 1540 CE). The Greek and Roman myths imply on-going star formation, but only recurrent events were thought important in their more serious writings. However, Chinese (and later Japanese and Korean) writings and star maps are highly valuable (Stephenson & Green 2002). Their authors kept track of planetary positions, eclipses, meteors, comets, and new stars of various types. The most firmly established examples happened in 1006 (also seen from Switzerland), 1054 (also one Arabic record), 1181, 1572 (also Tycho), 1604 (also Kepler), and 1987A in the Large Magellanic Cloud. There are possible or probable events from 70, 185, 369, 386, 393 and 837 CE; a couple of southern supernova remnants are less than 2000 years old. Yet it remains an abiding puzzle that there is no general agreement over records of the event (in about 1685) that gave birth to the radio source Cas A.

The known remnants lie close to the galactic plane (the Crab, SN 1054, is furthest, at $\sim 5°$ south). What they teach us is that, first, they are all different (Branch & Wheeler 2017; Alsabti & Murdin 2017). Secondly, supernovæ really do add to the heavy element inventory of the Galaxy. The Suzuku X-ray spectrum of the 1006 event is bristling with emission features of O, Ne, Mg, Si, S, Ar, Ca and Fe. The same can be said of the XMM Newton X-Ray spectrum of Tycho's remnant. The 1054 remnant includes a solar mass or more of hydrogen, which would have been conspicuous in peak-light spectra, agreeing with its central neutron star, PSR0532, and identifying it as a core-collapse event. The peak-light spectra of Tycho (1572) and of the Cas A birth event can be studied through light echoes. Dust clouds near the SN events have reflected peak light to us with multi-century delays. Cas A bore a definite resemblance to the bright SNII 1993J, complete with helium and hydrogen, while SN 1572, devoid of hydrogen then as now, resembled SN 1994D and others (Krause 2008; Krause *et al.* 2008). A couple of the historical remnants are sources of Ti-44 decay gamma rays – additional evidence of nucleosyntheses in SN events – as have been the gamma rays and radioactive-decay powered light curve of SN 1987A.

Future large surveys are expected to yield thousands of events per year, and should yield much better statistics on rates, types and parent populations, examples of rare sub-and super-luminous types, double detonations, and unusual environmental effects.

We may also expect answers to the deepest ongoing SN questions: (1) Are the progenitors of nuclear explosions white-dwarf pairs that merge or white dwarfs that accrete from some other sort of companion? and (2) What is the mechanism that kicks off the outer layers of core-collapse events? A Type II event in the Milky Way would provide a flood of neutrinos (compared to about a few tens from SN 1987A), and an unpredictable flux of gravitational waves. The most likely nearby progenitors are Betelgeuse and Antares.

2. Transient Astronomical Phenomena in Australian Indigenous Oral Traditions: 65,000 years of Oral History

Historical novæ and supernovæ are well recorded in the written records of cultures across Eurasia (Stephenson & Green 2002). Such brightly visible objects would also have been observed by Indigenous peoples across the world and probably incorporated into their oral traditions and material culture. However, demonstrating this poses a number of significant challenges. Oral traditions encode knowledge in narrative forms, while motifs in material culture, such as paintings and rock art, are open to interpretation without the producers of that art telling us what it means. The prospect of finding Indigenous traditions of novæ and supernovæ is an attractive one, but also one that has succumbed to speculation, conjecture, and pseudoscience in the literature. The most famous example is of the alleged depiction of SN 1054 in Anasazi rock art in SW USA (Brandt *et al.* 1975). Although the evidence was sketchy, the idea caught on and has now become an established "fact" that is wildly popular with the public. The Proceedings in which that paper was published included a full refutation article on the next page (Ellis 1975), which systematically demonstrated that the supernova interpretation was incorrect. However, that second paper is almost never mentioned or cited and seems to have been ignored.

This poses a problem whose solution can be addressed by the development of rigorous selection criteria for determining the validity and support of novæ and supernovæ claims in oral traditions and material culture. Hamacher (2014) offered a detailed methodology showing that despite a number of claims published in the literature, not one had sufficient evidence to conclude that the tradition or motif was that of a known nova or supernova. The only example that was vindicated related to Boorong Aboriginal traditions of western Victoria in Australia. In the 1840s, William E. Stanbridge learned about the local astronomical traditions of the Boorong clan (Wergaia language group) near Lake Tyrell, Victoria (Hamacher & Frew 2010). The Aboriginals who taught him their knowledge claimed to be the most skilled astronomers in the region. His paper (Stanbridge 1858) listed around 40 astronomical objects and provided a brief description of each. One was of a bright red star in Robur Carolinium, and although it was not listed in his catalogue he provided a description of it, its location, and a catalogue number of what he thought it might be. It proved to be a description of the luminous blue variable star Eta Carinae during its Great Eruption in the late 1830s and early 1840s. Its identity was proved conclusively during its "supernova impostor" event thanks to the details provided by Stanbridge from his Aboriginal informants.

Other Aboriginal traditions from Australia describe, for example, the bright appearance of stars in the Milky Way (Wells 1973). The stars attributed to sky ancestors were located in the tail of Scorpius, where known historical supernovæ such as SN 393 appeared. The evidence is not conclusive and other novæ candidates could also explain it, but it does offer important information about possible novae and supernovæ observations by Indigenous people around the world. But although those traditions are important, we must also be vigilant that we do not plant false or misleading conclusions into the public sphere (Schaefer 2006). That can cause degradation of traditional knowledge, and fuel speculation that can easily become established "fact" in scientific discourse, despite evidence to the contrary. This requires careful and robust scholarship, and calls for the community (a) not to publish scholarship without strong supporting evidence, and (b) to reject unfounded or refuted claims.

3. Historical Observations of Novae: Guest Stars to Glass Plates

Two examples are documented in which modern observations have been matched with the "guest stars" mentioned in historical records. The first is Nova Sco 1437, recorded by Korean royal astronomers in the Sejong Sillok, a chronicle of King Sejong's reign from 1418–1464 CE. Visible for 14 days, the guest star was located "between the second and third stars of Wei. It was nearer to the third star, about half a chi away". Previous modern interpretations had placed that location just north of ζ Sco, but searches for nova shells or other signs of nova activity in the relevant region showed nothing. However, a new numbering of the stars in Wei, starting with μ Sco (the determinant of the mansion) places the guest star just *east* of ζ Sco, where a cataclysmic variable (CV) and nova shell are in fact located. However, there is no confirmation available that this numbering was indeed applied by Korean astronomers in historical times. In quiescence the CV is visible on scans of the Harvard College Observatory plate archives dating from the 1920s to the 1950s. An image of the system on plate A12425 (taken on 1923 June 10 in Arequipa, Peru) was used in conjunction with modern observations (made using the Swope 1-m telescope at Las Campanas in 2016 June) to obtain a long-baseline measurement of the proper motion of the CV, finding $\mu_\alpha = -12.74 \pm 1.79$ milliarcseconds per year and $\mu_\delta = -27.72 \pm 1.21$ milliarcseconds per year. Accounting for that motion shows that the location of the CV in 1437 CE coincided with the centre of the nova shell, providing strong evidence of a causal link between the two, and linking the CV to the guest star in the Korean records. The Harvard plates also show dwarf nova eruptions in this system in 1934, 1935, and 1942, providing data that can be used to test theories, such as Hibernation (Shara *et al.* 1986), that seek to explain the connections between the various types of events that occur on or near massive white dwarfs (novæ, dwarf novæ, and thermonuclear supernovæ).

The second example is BK Lyn, a nova-like CV identified in 1986 and since linked to a guest star that appeared on 101 December 30 and was listed in Chinese records. BK Lyn has been heavily monitored by members of the Centre for Backyard Astrophysics. It transitioned from a nova-like CV to an ER UMa-like dwarf nova in 2005, but now appears to have entered a standstill phase, possibly similar to that of Z Cam-type stars; no dwarf nova outbursts have been seen since 2012. Further details about Nova Sco 1437 can be found in Shara *et al.* 2017, and on BK Lyn in Patterson *et al.* (2013). The combination of data from ancient records, archived plates and modern observations is clearly a powerful tool for understanding the life cycles of accreting white-dwarf binaries.

4. Evidence of Galactic Supernovæ from Natural Terrestrial Archives?

Asian records of historical guest stars have been linked to Antarctic ice-core records. (The issue of nitrate concentrations was discussed in a poster paper by Tanabe). One suggestion is that a rise in terrestrial radiocarbon seen in CE 1009 could have been caused by SN 1006 (Damon *et al.* 1995): if a large flux of gamma rays had been provided by SN 1006, they could have produced terrestrial radiocarbon which was incorporated into tree rings a few years later (via the carbon cycle). However, it may also be possible that normal variations in solar activity (from a Schwabe cycle maximum in the first half of the first decade of the 11th century to a Schwabe cycle minimum a few years later) led to an increase in radiocarbon from around CE 1005 to 1010. This example shows that reconstructing solar activity is also important for the study of supernovæ.

5. The Expected Accuracy of Classical Nova Identifications among Historical Far-Eastern Guest Star Observations

It is clearly important to assess the probability that identifications of classical novæ among historical Far Eastern guest star observations are correct. The approach adopted by Vogt, Hoffmann, Neuhäuser *et al.* (poster paper) was to compare the coordinates of eight supernovæ derived by Stephenson (1976) and Clark & Stephenson (1977) from information given in old texts with those of the corresponding modern supernova remnants. It yielded a typical angular difference of the order of 0.3 to 7 degrees. That value could then be adopted for the expected deviation in coordinates between a classical nova observed as a guest star and its modern counterpart among known cataclysmic variables. However, there are considerable disagreements among modern authors over the interpretation of ancient Far Eastern texts, emphasizing the need to consult again the original sources in order to improve the positional reliability.

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