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Transient X-ray Binaries in the Magellanic Clouds and Milky Way

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Abstract. This contribution gave three examples of X-ray transients in the Magellanic Clouds and the Milky Way that have been observed as part of the SALT Transients Large Programme. The transients (SMC X-3, MAXI J1957+032 and ASASSN-16oh) have been triggered from both space-based wide-field monitoring facilities (*Swift*/XRT, MAXI) and ground-based ones (ASASSN, the All Sky Automated Survey for SN), providing insights into the physics of super-Eddington accretion onto neutron stars and white dwarfs, and also into the long-term properties of accreting millisecond X-ray pulsars.

Keywords. Accretion, accretion disks, stars: novæ, cataclysmic variables, X-rays: general

1. Introduction

The detection and monitoring of Galactic/Magellanic Cloud X-ray transients (XRTs) is now well served by MAXI, *Swift*, INTEGRAL and other X-ray satellites; their follow-ups and detailed studies fit extremely well into the SALT 100% Q-scheduled mode of operation (Charles *et al.*, page 240). As a result, there has been a SALT Large Programme (Buckley, page 176) on Transients underway since 2016, with a component dedicated to X-ray binary transients. The latter come in a variety of forms, from Low-Mass X-ray Binaries (LMXBs) containing either black holes (all of which are transient; Belloni *et al.* 2011) or neutron stars (NS, some are transient; Campana *et al.* 1998), to High-Mass X-ray Binaries (HMXBs) containing NSs (all are BeX pulsar transients; Reig 2011), and white-dwarf compact binaries, particularly the supersoft systems (SSS), so called because of their extremely low X-ray temperatures ⩽100eV (Kahabka & van den Heuvel 2006).

The current populations of X-ray binaries include ∼140 HMXBs and 190 LMXBs in the Milky Way, and ∼130 HMXBs, 1 LMXB and a dozen SSS in the Magellanic Clouds (Coe *et al.* 2009). Those numbers are surprising, given that the Clouds have <1% of the mass of the Milky Way, but are in fact strong evidence of the recent bursts of star formation that have affected the Clouds.

The LMXB transients, containing either a NS or a BH, have orbital periods of hours to a few days, but are only discovered through their rare X-ray outbursts, which are often decades or more apart. They frequently approach, or sometimes exceed, the Eddington Luminosity; they last for weeks to months, and usually decline exponentially after a few months (Charles 2011). The HMXB transients include virtually all early-B emission

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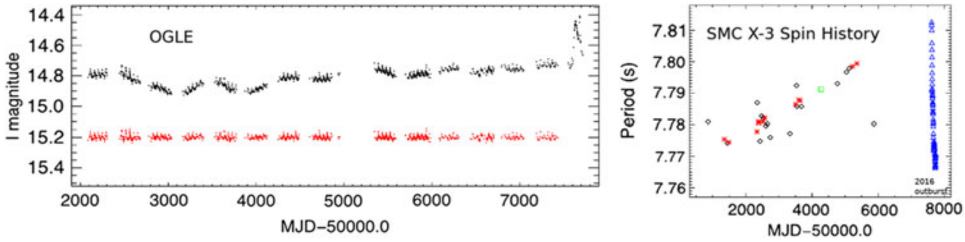

Figure 1. *Left:* 16-yr OGLE light-curve of SMC X-3, showing the regular orbital (45d) outbursts and the Type II 2016 super-Eddington event. *Right:* Spin history of SMC X-3 over 20 years, showing the rapid spin-up (*Swift*, triangles) during the 2016 outburst. Both figures from Townsend *et al.* (2017).

systems (BeX), which display regular optical and X-ray activity (Type I outbursts) over the orbital period of weeks to months, and much more rarely show very large, extended outbursts (Type II). All are X-ray pulsars, with spin periods of seconds to minutes (Coe *et al.* 2009). The talk was illustrated with three examples: LMXB and HMXB NS transients, and an SSS.

2. SMC X-3

For 15 years RXTE undertook regular monitoring of the SMC to identify new BeX outbursts. Their locations and identifications required follow-up observations by other missions, and since 2016 that has been undertaken by the *Swift* SMC Survey (S^3, Kennea *et al.* 2016); its 142 1-min pointings each week detect all X-ray sources above 10^{36}erg s^{-1}. So far this has yielded 7 new BeX SXPs in outburst, one of which was SMC X-3 in an extremely luminous Type II outburst ($L_X \sim 1.2\times10^{39}$erg s^{-1}), i.e., at ∼10× the Eddington Limit for a canonical NS. That intense period of high accretion significantly spun-up the NS (Townsend *et al.* 2017) and produced a substantial optical outburst superimposed on the long-term orbital outbursts: see the OGLE light-curve in Fig. 1.

SALT spectra taken at this time showed He II λ4686 Å emission from a transient accretion disc that had formed around the pulsar, plus strong Balmer emission from the extended equatorial disc around the rapidly rotating Be primary. Thus, for the duration of this outburst, SMC X-3 exhibited discs around both binary components. Further details are given by Townsend *et al.* (2017). Systems like these have taken on renewed significance with the recent discovery that some ultra-luminous X-ray sources (ULXs) are pulsars, exceeding the Eddington Limit by more than a factor of 100. Such extragalactic optical counterparts are almost impossible to study, so the SMC BeX systems provide an ideal ‘local’ laboratory to probe the physics of pulsar accretion at extremely high rates.

3. MAXI J1957+032

This high-latitude XRT, hereafter J1957, was observed by MAXI to undergo 4 hard X-ray outbursts of extremely short duration (<5d), three of which were followed up in detail by *Swift*. That resulted in an optical identification with a faint stellar counterpart (peak V∼17) which is not visible on the DSS, and hence underwent a $\Delta V>5$, indicating it must be an LMXB and not a BeX (Mata Sánchez *et al.* 2017). The rapidity of these events in both X-ray and optical wavelengths is shown clearly in Fig. 2, and represents serious logistical constraints for follow-up work.

Those rapid events are very similar to the outbursts of accreting millisecond X-ray pulsars (AMXPs), of which J1808.4 is a prototype. As shown by Wang *et al.* (2001), AMXPs start an apparently normal decline from the initial X-ray peak, then suddenly enter a steep decline; the cause is attributed to the way the magnetospheric barrier

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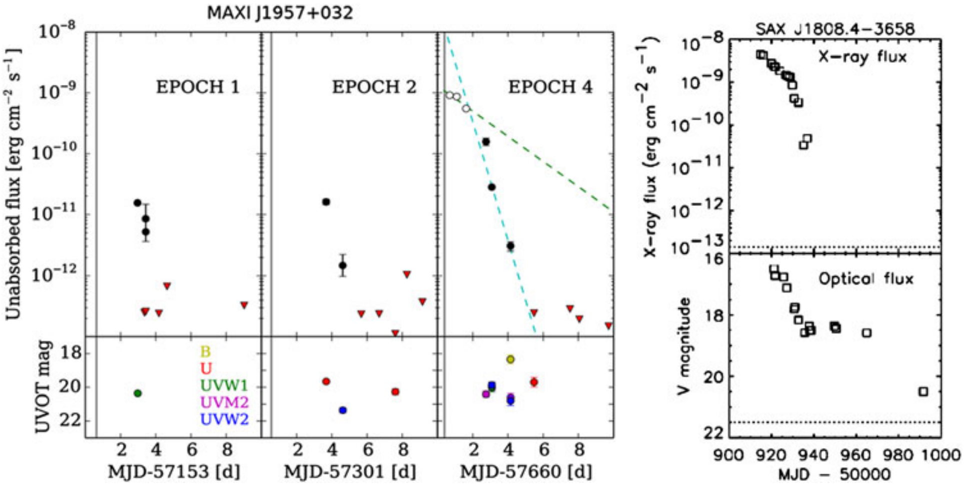

Figure 2. *Left: Swift* observations at X-ray (upper boxes) and UV/optical (lower boxes) wavelengths of 3 of the 4 MAXI-detected outbursts of J1957; from Mata Sánchez *et al.* (2017). *Right:* X-ray and optical observations of the 1998 outburst of the AMXP SAX J1808.4-3658. The dotted lines show the quiescent levels. From Wang *et al.* (2001) (*reproduced with kind permission*).

presented by the rapidly rotating NS prevents further accretion once the mass accretion rate drops below a critical level. Such behaviour has now been seen in a number of systems, particularly NGC 6440X2 (Heinke *et al.* 2010). By interpreting J1957 as an AMXP, one can infer a distance of ∼7kpc, based on the JvP–McC relation between X-ray and optical luminosities and orbital period. Confirmation of that model will require rapid follow-up observations of a new J1957 outburst with the ASTROSAT LAXPC to search for millisecond pulsations, although a sufficiently sensitive search might find it as a radio pulsar in quiescence.

4. ASASSN-16oh

Discovered by ASAS-SN (the All Sky Automated Survey for SuperNovæ), this new SMC transient was in an OGLE field, and in fact the OGLE light-curve revealed that its rise to maximum began almost 6 months earlier (Mroz *et al.* 2016). However, the light-curve rise is extremely smooth, and the first SALT spectra revealed very strong, narrow He II and Hα emission, but no absorption features (see Fig. 3). X-ray follow-ups by *Swift* showed that ASASSN-16oh was a newly discovered SSS, peaking at almost 10^{37}erg s^{-1} and with kT ∼80eV (Maccarone, Brown & Mukai 2016). Subsequent SALT spectra yielded He II radial velocities that varied, albeit with low amplitude, indicating a period of either several hours or several days, similar to other SSS objects in the Magellanic Clouds.

The standard paradigm for SSS objects (see. e.g., Kahabka & van den Heuvel 2006) involves super-Eddington mass-transfer rates onto the WD, which undergoes thermonuclear fusion on its surface, thereby achieving the very high luminosities observed (accretion onto a white dwarf delivers much less). When accreting at somewhat lower rates, the WD should undergo unstable burning (Kato 2010) and appear as a nova shell. However, none of the SALT spectra showed any nova features, thereby generating a remarkable puzzle regarding our understanding of the SSS phenomenon. Furthermore, none of the SSS objects in the Clouds has a spectroscopically identified donor, except for the long-period symbiotic systems. Perhaps ASASSN-16oh, once it is in full quiescence, may finally assist us.

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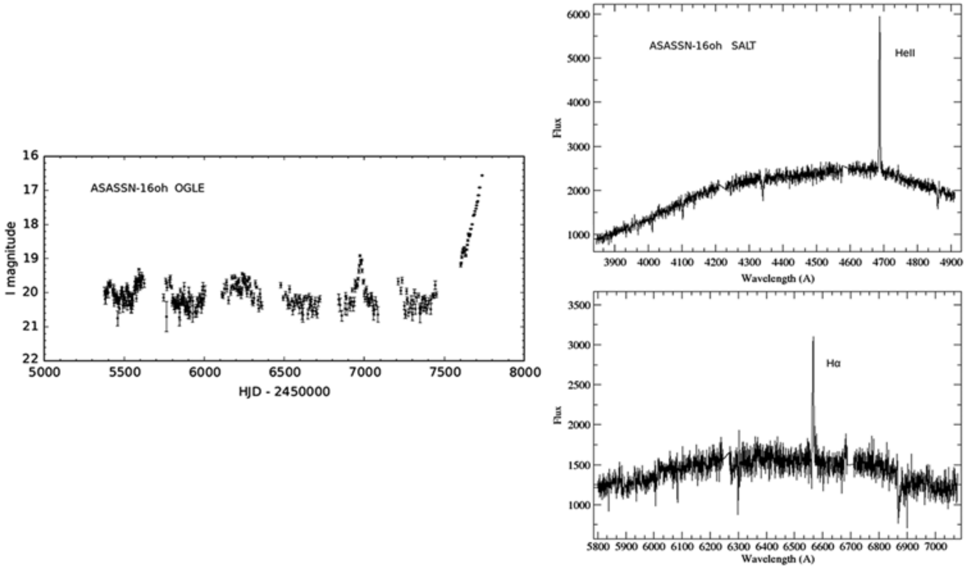

Figure 3. *Left:* OGLE I-band light-curve of ASASSN-16oh, showing the lead-up to its Dec. 2016 outburst. *Right:* SALT RSS spectra of ASASSN-16oh around the outburst peak.

5. Conclusions

These three examples demonstrate the strength of SALT's fully Q-scheduled operations for studying XRTs. They also show the importance of adding substantially more rapid spectroscopic follow-up capabilities as the new survey missions (ZTF, LSST, MeerKAT/SKA and others) begin over the next decade. It is all very well finding transients, but without spectroscopy it is much harder to interpret them.

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