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The Catalina Real-time Transient Survey

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Abstract. The Catalina Real-time Transient Survey (CRTS) currently covers 33,000 deg^2 of the sky in search of transient astrophysical events, with time base-lines ranging from 10 minutes to $\sim$ 7 years. Data provided by the Catalina Sky Survey provide an unequalled base-line against which $> 4,000$ unique optical transient events have been discovered and openly published in real-time. Here we highlight some of the discoveries of CRTS.

Keywords. (stars:) supernovæ: general, (galaxies:) BL Lacertae objects: general, stars: dwarf novæ stars, stars: flare, galaxies: dwarf

1. Introduction

For the past four years the Catalina Real-time Transient Survey (CRTS; Drake *et al.* 2009a, Djorgovski *et al.* 2011, Mahabal *et al.* 2011) has systematically surveyed tens of thousands of square degrees of the sky for transient astrophysical events. CRTS discovers highly variable and transient objects in real-time, making all discoveries public immediately, thus benefiting a broad astronomical community. Data are leveraged from three telescopes, operated by LPL in a search for NEOs; they cover up to ∼2,500 deg^2 per night with four exposures separated by $\sim$ 10 mins. The total survey area is $\sim$ 33,000 deg^2 and reaches depth $V \sim 19$ to 21.5 mag (depending on the telescope) during 23 nights per lunation. All data are automatically processed as they are taken, and optical transients (OTs) are immediately distributed using a variety of electronic mechanisms (see http://www.skyalert.org/ and http://crts.caltech.edu/). CRTS has so far discovered $>$ 4,000 unique OTs including $> 1,000$ supernovæ and 500 dwarf novæ.

2. Discoveries

Supernovæ and their hosts. Supernovæ are both cosmological tools and probes of the final states of stellar evolution. While many astronomical surveys focus on Type Ia SNe (being standard candles), CRTS uses its wide-area coverage to look for rare types of events that may be missed by many traditional SN surveys. With $> 1,000$ SNe (CRTS published more SN discoveries in both 2009 and 2010 than any other survey), this data set has allowed us to carry out a systematic exploration of supernovæ properties, leading to the discovery of extremely luminous supernovæ and supernovæ in extremely faint host galaxies, with $M_V \sim -12$ to -13, i.e., ∼0.1% of L_*.

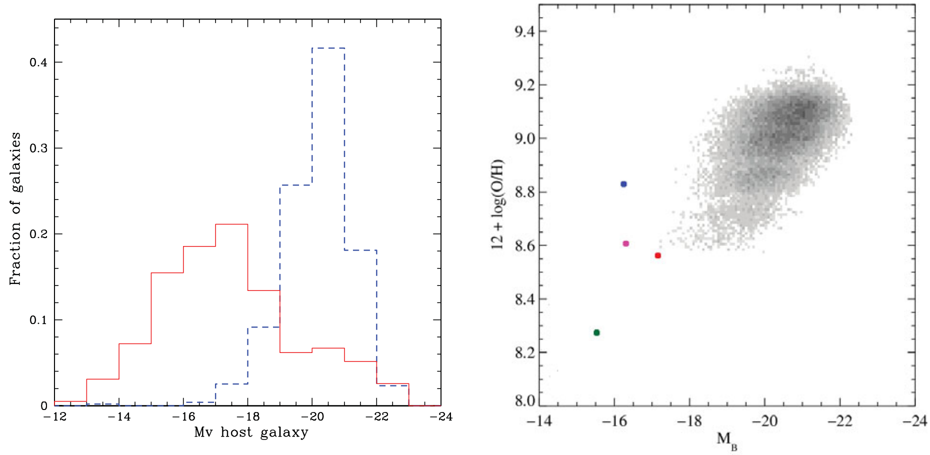

Figure 1. SN Hosts. Left: A comparison of supernovæ host-galaxy absolute magnitudes. Solid line: CRTS. Short-dashed line the Lick Observatory Supernovæ Search (LOSS). Right: Host luminosity and metallicity for four energetic Type IIn SN host galaxies, compared with 53,000 star-forming galaxies from SDSS (Tremonti *et al.* 2004).

Two especially interesting classes of luminous SNe discovered by CRTS, ROTSE and PTF include luminous Type Ic SNe: SN 2005ap (Quimby *et al.* 2007), SN 2009de (Drake *et al.* 2009b, 2010), SN 2009jh (Drake *et al.* 2009, Quimby *et al.* 2011), SN 2010gx (Mahabal *et al.* 2010; Pastorello *et al.* 2010a, 2010b), and CSS110406:135058+261642 (Drake *et al.* 2011b) and ultra-luminous and energetic Type IIn SNe: SN 2008fz, SN 2009jg, etc. (Drake *et al.* 2009c, 2010, 2011a). These supernovæ have been found to favour extremely faint host galaxies (Drake *et al.* 2009a, 2010), suggesting the importance of host-galaxy environment and explaining why more such events have not been discovered previously. In Fig. 1 we contrast the SN host-galaxy absolute magnitudes (from CRTS) with those from the long-running Lick Observatory SN Search (LOSS; Filippenko *et al.* 2001) which concentrates on large nearby galaxies.

The rate of our SN discovery in intrinsically faint galaxies implies phenomenally high specific SN rates (Drake *et al.* 2009a). Although such galaxies are common, a very small fraction of all baryonic matter is expected in them (Kauffmann *et al.* 2003). Evidence suggests that those galaxies include blue compact dwarfs and irregular dwarfs, where excessive star formation rates accelerate SNe rates for the most rapidly evolving massive stars (progenitors of luminous SN). The presence of additional evidence for enhancements in SN Ia rates, of up to 1500%, has been speculated by Della Valle & Panagia (2003).

It is likely that these dwarf galaxies have low metallicities owing to a delayed onset of star formation and expulsion of enriched SN ejecta from their shallow potential wells. According to the galaxy mass-metallicity relationship (Tremonti *et al.* 2004), low-luminosity hosts are expected to be low-metallicity hosts. This prediction was recently confirmed in the work of Neill *et al.* (2011), Stoll *et al.* (2011) and Kozlowski *et al.* (2010) as well as in our recent work shown in Fig. 1. Low metallicities are speculated to lead to a top-heavy IMF, which would account both for an enhanced specific SN rate and for the propensity for highly luminous events (from high-mass progenitors). Low-metallicity host galaxies are also linked to the broad-line type-Ic hypernovæ associated with long-timescale GRBs (Stanek *et al.* 2006).

Another interesting discovery involves a new class of SNe that may be associated with AGN accretion disks. Possibly the most luminous and optically energetic SN ever discovered, CSS100217 (within the AGN disk of a bright NLS1 galaxy), demonstrates that extreme supernovæ can occur in a variety of extreme environments (Drake *et al.* 2011a).

Blazars. Highly variable optical and radio sources, blazars are often targeted for optical follow-up at other wavelengths after their outbursts. CRTS provides an unbiased, statistical optical monitoring of known blazar sources over 75% of the sky. Owing to the erratic nature of blazar variability and the association of those sources with previously catalogued, and often faint, radio sources, we have found several tens of likely blazars based in transient outburst events. We have also discovered variability-selected blazar counterparts to the previously unidentified FERMI gamma-ray sources. CRTS data are being combined with radio data from the Owens Valley Radio Observatory, and will be used to provide better constraints to the theoretical models of blazar emission and variability.

Dwarf Novæ and UV Ceti variables. CRTS has discovered more than 500 new dwarf-nova-type cataclysmic variables (CVs). Since those objects are found in real time, the outbursts are often followed up. Thus far, 132 CV discovery alerts have been sent to users of the VSNET system (www.kusastro.kyoto-u.ac.jp/vsnet/), resulting in successful period determination in dozens of systems. Similarly, CRTS has discovered over 100 UV Ceti variables (flare stars), varying by several magnitudes within minutes. The rate of such flares is still poorly constrained, and must be understood so that future surveys can find rare types of rapid transients. The short cadence of CRTS is well tuned to the discovery of such events. Another class of rapid transients are eclipses of white-dwarf binary systems, which probe the end state of stellar binary evolution. Although first discovered in real time, archival searches have revealed dozens more such eclipsing systems, including some with low mass companions (Drake *et al.* 2011c).

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