The Catalina Real-time Transient Survey

A.J. Drake¹, S.G. Djorgovski^{1,6}, A. Mahabal¹, J.L. Prieto²,
E. Beshore⁴, M.J. Graham¹, M. Catalan³, S. Larson⁴,
E. Christensen⁵, C. Donalek¹ and R. Williams¹

¹California Institute of Technology, Pasadena, CA 91125, USA. email: ajd@cacr.caltech.edu

²Dept. of Astrophysical Scinces, Princeton University, NJ 08544, USA.
³Depto. de Astronomia y Astrofisica, Pont. Uni. Catolica de Chile, Santiago, Chile.
⁴Lunar and Planetary Lab, University of Arizona, Tucson, AZ 85721, USA.
⁵Gemini South Observatory, c/o AURA, Casilla 603, La Serena, Chile.
⁶Distinguished Visiting Professor, King Abdulaziz Univ., Jeddah, Saudi Arabia.

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 baselines ranging from 10 minutes to ~ 7 years. Data provided by the Catalina Sky Survey provides an unequaled baseline 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:) supernovae: general, (galaxies:) BL Lacertae objects: general, stars: dwarf novae 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 is leveraged from three telescopes used in a search for NEOs, operated by LPL, which cover up to $\sim 2,500~{\rm deg^2}$ per night with four exposures separated by ~ 10 mins. The total survey area is $\sim 33,000~{\rm deg^2}$ and reaches depth V ~ 19 to 21.5 mag (depending on 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 supernovae and 500 dwarf novae.

2. Discoveries

<u>Supernovae and their hosts</u>. Supernovae 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 supernova properties leading

2 Drake et al.

to the discovery of extremely luminous supernovae and supernovae in extremely faint host galaxies, with $M_V \sim -12$ to -13, i.e., $\sim 0.1\%$ of L_* .

Two especially interesting classes of luminous SNe discovered by CRTS, TSS 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. 2009c, 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 supernovae have been found to favor 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 Figure 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 bright 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 these 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). Additional evidence for enhancements in the rates of SN-Ia, up to 1500%, has been speculated by Della Valle & Panagia (2003).

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

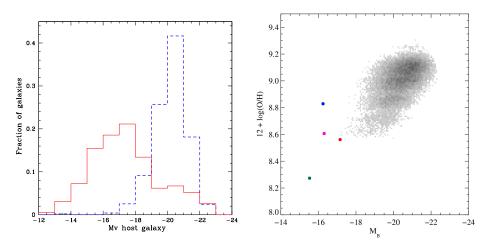


Figure 1. SN Hosts. Left: A comparison of supernova host-galaxy absolute magnitudes. Solid line: CRTS. Short-dashed line the Lick Observatory Supernova Search (LOSS). Right: Host luminosity and metallicity for four energetic type IIn SN host galaxies, compared with 53,000 star-forming galaxies from SDSS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

CRTS 3

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

<u>Blazars</u>. Blazars are highly variable optical and radio sources. They are often targeted for optical follow-up after their outbursts at other wavelengths. CRTS provides an unbiased, statistical optical monitoring of known blazar sources over three quarters of the sky. Due to the erratic nature of blazar variability and the association of these sources with previously cataloged, and often faint radio sources, we have found several tens of likely blazars based on transient outburst events. We have also to produce variability-selected blazar counterparts to the previously unidentified $Fermi~\gamma$ -ray sources. CRTS data are also 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.

<u>Dwarf Novae and UV Ceti variables</u>. The CRTS project has discovered more than 500 new dwarf nova type cataclysmic variables (CVs). Since these objects are found in real-time, the outbursts are often followed. Thus far, 132 CV discoveries have been alerted to users of the VSNET system (www.kusastro.kyoto-u.ac.jp/vsnet/), resulting in successful period determination in dozens of these 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 these events. Another class of rapid transients are eclipses of white dwarf binary systems. These systems probe the end state of stellar binary evolution. Although first discovered in real-time, archival searches revealed dozens more eclipsing systems, including some with low mass companions (Drake et al. 2011c).

<u>Acknowledgments</u>. CRTS is supported by the NSF grant AST-0909182. We thank the personnel of many observatories involved in the survey and the follow-up observations.

References

Della Valle M., & Panagia, N. 2003, ApJ, 587, L71

Drake A.J., et al. 2009a, ApJ, 696, 87

Drake A.J., et al. 2009b, CBET, 1958

Drake A.J., et al. 2009c, *CBET*, 1766

Drake A.J., et al. 2010, ApJ, 718, 127

Drake A.J., et al. 2011a, APJ, 735, 106

Drake A.J., et al. 2011b, ATEL, 3343

Drake A.J., et al. 2011c, ApJ, arXiv:1009.3048

Djorgovski, S. G., et al. 2011, JAXA, in press, arXiv:1102.5004

Filippenko, A., Li, W.D., Treffers, R.R., & Modjaz, M. 2001, PASP Conf Ser., 246, 121

Kauffmann G., et al. 2003, MNRAS, 341, 33

Kozlowski, S., et al. 2010, ApJ, 722, 1624

Mahabal, A. et al. 2009, $ATEL,\,1713,\,1$

Neill J., et al. 2011, ApJ, 727, 15

Pastorello, A. et al 2010a, CBET, 2413

Pastorello, A. et al 2010b, ApJ, 724, 16L

Quimby, R. et al. 2007, ApJ, 668, 99

Quimby, R. et al. 2011, NATURE, 474, 487

Stanek, K.Z., et al. 2006, AcA, 56, 333

Stoll, R., et al. 2011, ApJ, 730, 34

Tremonti, C. et al. 2014, ApJ, 613, 898